HUBBARD

HIGHWAY INSPECTORS' HANDBOOK

WORKS OF

PRÉVOST HUBBARD

CHEMICAL ENGINEER

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HIGHWAY INSPECTORS' HANDBOOK

BY

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PREFACE

ALTHOUGH this handbook has been prepared primarily for the use of inspectors, it is hoped that it may also prove of service to engineers and contractors. The author has endeavored to present most of the important details of highway construction and maintenance, as briefly as possible, in such form as to be quickly available to the Inspector, who wishes to be told what to do rather than what others have done under various conditions. It has, of course, been necessary to include considerable explanatory matter in order that he may follow directions and suggestions intelligently.

In place of tables, so commonly found in most handbooks, the author has made use of a large number of diagrams in order to save space and present data in convenient form for field use. These diagrams have been prepared from the most reliable data that he has been able to secure, from his own experience and from various records of work done throughout the country. On some subjects, however, the available information is very limited, and criticisms and comments will be appreciated from engineers who may have occasion to refer to certain of these diagrams and find that the values given vary from their own experience under a given set of conditions.

Throughout the volume, each general subject has been divided into articles, numbered consecutively, and frequent cross references will be found to articles in other parts of the book. All cross references are indicated in the text by the insertion of an article number in parenthesis.

It is realized that the field of highway engineering has been well covered by a number of excellent text and reference books, but the subject of adequate inspection has never been

dealt with as fully as its importance warrants. Many costly failures in the past would undoubtedly have been prevented had the work received proper and intelligent inspection. Much unsatisfactory work in the future will be prevented if adequate inspection is furnished. It is hoped, therefore, that this little volume will meet a real need in the profession of highway engineering.

PRÉVOST HUBBARD

May 19, 1919

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HIGHWAY INSPECTORS' HANDBOOK

CHAPTER I

HIGHWAY INSPECTION

THE INSPECTOR

1. Highway Inspection. Webster defines *inspection* as "a careful viewing or examining to ascertain quality or condition," and an *inspector* as "one to whose care the execution of any work is committed, for the purpose of seeing it faithfully performed." *Faithful* performance presupposes work done in accordance with a definite understanding or under stipulated conditions. In highway work the stipulated conditions are usually covered by written or printed specifications which should always be incorporated in the contract if the work is done under contract. The highway Inspector should, therefore, possess and carry with him for reference a copy of the specifications covering work which he is inspecting. His first duty is to ascertain whether or not the conditions of the specifications are being fulfilled at all stages of the work.

2. Qualification of Inspectors. An inspector should first of all possess sufficient knowledge of the work which he inspects to thoroughly understand the requirements of the specifications covering the work. This frequently necessitates a certain amount of experience. No matter how

intelligent he may be, a perfectly green man will seldom make a good inspector. Before being placed in charge of important inspection he should, therefore, have acquired some experience in highway work under a competent inspector. He should possess good judgment and tact and should be keenly observant, as the slighting of apparently minor details of the work may result in unsatisfactory conditions which cannot be easily remedied. He should be conscientious, loyal, and capable of standing up for what he believes to be right in the face of persuasion or opposition. He should have a well balanced understanding of his authority and the limits of his authority and should fully appreciate his responsibilities.

3. Responsibility of Inspectors. While the Engineer is in responsible charge of the work it is impracticable for him to be on the job at all times. He is, therefore, obliged to delegate a portion of his responsibility, that of detailed observation, to the Inspector. The Inspector, then, first of all, serves as the eyes of the Engineer for features of the work to which the Engineer is unable to devote his continual attention. It is practically impossible from the visual examination of newly completed work to ascertain whether or not such work has been done in the satisfactory manner, and with the satisfactory materials presumably covered by the specifications. The work upon its face may appear satisfactory and ultimately show defects which conclusively prove that it could not have been done in accordance with specifications. At such times it may be too late to hold the Contractor responsible. Noting all evidences of unsatisfactory workmanship and materials which he has observed and which have not been corrected by the Contractor is the principal responsibility of the Inspector. In case it should develop that the specifications are faulty in any respect this fact should also be noted so that if desired a satisfactory adjustment may be made between the Engineer and the Contractor. There are three general classes

of inspection, one or more of which are necessary in road and paving work. These are laboratory inspection, plant inspection, and roadside inspection.

CLASSES OF INSPECTION

4. Laboratory Inspection. Laboratory inspection is largely confined to the examination or testing of road materials for the purpose of ascertaining whether or not they conform with specifications. In certain instances it may also serve to indicate whether methods of work have been carried out in accordance with specifications, as in the examination of a sample of bituminous concrete, or a section of the completed highway. The laboratory Inspector may be called upon to conduct both involved chemical and physical tests and, for this reason, may properly be a trained chemist, testing engineer or chemical engineer. He may, to some extent, deal directly with the Engineer, plant Inspector or roadside Inspector. His duties are more or less specialized, and except as they relate to other classes of inspection, will not be considered in this handbook.

5. Plant Inspection. Plant inspection has to do with plant sampling and testing of road materials, measurements of quantities and often control of proportions of materials, temperature observations, and the inspection of such portions of the plant methods of operation and procedure as may be covered by specifications or may materially affect the character and quality of the work. Plant inspection of materials is usually limited to visual inspection and a few simple physical tests, which check or are eventually checked by the laboratory. Irrespective of the character of work performed, there are four functions of a plant, one or more of which may require inspection. These are receiving, storing, preparing and distributing or shipping materials. There are two classes of plants, those in which certain individual constituents of a road or pavement are

prepared or handled, and those in which the paving material proper is prepared. As an example of the former may be mentioned petroleum, asphalt or tar refineries where bituminous road materials are manufactured. When conditions warrant, an inspector may be placed at such a refinery to sample the manufactured product, observe its storage, seal, open and reseal storage tanks, measure quantities, mark or stamp containers, watch the loading of shipments of approved materials, and seal cars or containers. Among plants of the class which prepare or handle the paving material proper may be mentioned bituminous concrete or sheet asphalt paving plants, asphalt block plants, and creosoting plants engaged in the manufacture of creosoted wood paving blocks. At such plants the Inspector may sample and test not only the individual constituents of the pavement, but also the prepared paving composition and, in addition, observe and record certain details of its preparation. This is the most common class of plant inspection and is covered in detail in subsequent chapters.

6. Roadside Inspection. Roadside inspection covers either the field sampling and visual examination of the individual constituents of the road or pavement, or of the paving material proper, measurements of quantities and distribution of such materials as are received and placed upon the road, frequently temperature observations, and the inspection of such details of work as are included in the specifications or may be necessary to produce a satisfactory job. In some instances the paving material may be prepared at the site of work or at roadside plants. Where this is the case, the Inspector may have to assume the responsibility of both plant and roadside inspection. It frequently happens, however, that the plant may be located at a considerable distance from the work and that the services of at least two inspectors will be required to see that the work is faithfully performed in accordance with specifications. When this is so the two Inspectors should

work in harmony and keep in close touch with one another. Both plant and roadside inspectors may have occasion to submit samples of materials to the laboratory for examination as directed by the Engineer or requested by the Laboratory. They may also submit samples on their own initiative when they have reason to suspect that any material fails to conform with specifications, but do not possess adequate facilities for ascertaining whether or not their suspicions are well founded. Either may at times be called upon to sample and inspect natural deposits of material such as sand, gravel or rock. In addition to the inspection above described the Inspector may be called upon to examine and report upon the condition of a road or pavement any time after its completion. In some respects this is the highest class of inspection, as the Inspector then has but little to guide him in his work and must depend to a large extent upon his natural powers of observation and deduction, supplemented by his experience and possibly by a laboratory examination of sections of the pavement removed under his direction.

RELATIONS OF THE HIGHWAY INSPECTOR

7. The Engineer. The Inspector comes immediately under the authority of the Engineer and should take instructions from no one else unless so directed by the engineer. He should carry out the Engineer's instructions explicitly and give his loyal support to the observance of his directions, both as furnished by the specifications and as stated verbally. On the other hand, the Engineer should afford loyal support to his inspector if the latter keeps within the limits of his authority and exercises good judgment. In case of misunderstandings or errors on the part of the inspector, the Engineer should never reprimand him before the Contractor, foreman, or any of the working force. He should first of all see that his specifications are not only so

explicit that misunderstandings are practically eliminated, but he should also take precautions that they are technically correct so that no legitimate error will result in either the inspection or execution of the work. Unless the relations between the Inspector and Engineer are of long standing so that both are thoroughly familiar with each other's methods, the Engineer should invariably instruct the Inspector as to his limits of authority for each contract and furnish him with advance detailed directions regarding the conduct of his work if such directions are necessary. Finally the Inspector should be under the control of the Engineer to the same extent in public service work as in private engineering practice.

8. The Laboratory. The laboratory is a necessary adjunct to road and paving work, and, under the direction of the Engineer, may deal directly with the Inspector with regard to certain matters. In some cases, as for instance a bituminous concrete paving plant, the Inspector may himself conduct certain laboratory tests, but he should always rely upon a well-equipped chemical or testing laboratory to furnish the detailed examination of the materials which he inspects. In addition to this the control laboratory serves as a check upon the field tests made by the Inspector. The relations between the Laboratory and the Inspector should be clearly defined to each by the Engineer. Usually the Inspector samples all shipments of materials received and forwards them direct to the Laboratory, whose report of examination and acceptance he should obtain prior to their use in the work. In addition, throughout the work he may be required to send to the Laboratory check samples of materials which he tests and should keep himself informed as to how his own results compare with those of the Laboratory. He may at various times be requested by the Laboratory to submit special samples and if during the course of the work he has any reason to suspect the character of material which has already been

sampled and tested he should submit a new sample of such material. In case the Laboratory examination shows slight variations of a material from specification requirements the Laboratory should indicate upon its report to the Inspector whether or not the material will be accepted and, if so, with or without warning to the contractor. Such matters should, of course, be decided by the Engineer, who may prefer to personally communicate with the Inspector after conferring with the Laboratory.

9. The Contractor. (*a*) While the first duty of the Inspector is to see that the Contractor performs his work faithfully in accordance with the specifications, it is of the utmost importance for him to exercise good judgment and tact in his relations with the Contractor. To this end he should endeavor to delay or hinder the operations of the Contractor as little as possible, and should inspect materials promptly. He should never accept extraordinary favors from, nor obligate himself to the Contractor in any manner. On the other hand he should never allow the Contractor to work a modification or substitution of any details of the specifications unless such change has been made known to and first approved by the Engineer. The limit of his authority as related to the Contractor should be clearly defined by the Engineer both to him and to the Contractor so that there may be no conflict through misunderstandings. As a rule, the Inspector should never give orders to laborers on the work, but should deal directly with the Contractor or, in the Contractor's absence, with his foreman. Unless specifically authorized to do so by the Engineer he should not actually direct the Contractor, but should immediately notify him of any and all violations of the specifications. If the violation is not vital the work or material may be accepted with warning that further violation will cause rejection. In case of dispute as to the interpretation of specifications the matter should be immediately taken to the Engineer for decision.

(*b*) While the specifications should be technically correct and readily understandable, such is not always the case. It is, therefore, often good policy for the Engineer, Inspector and Contractor to hold a conference preceding the actual work and to review each requirement of the specifications until a common understanding is reached. Work should be suspended by direction of the Inspector only under conditions to be prescribed by the Engineer. The Inspector should keep a detailed diary of his observations throughout the work, noting particularly all warnings and instructions given to the Contractor. There are, of course, all classes of contractors from those who are conscientious and honest to those who are unscrupulous and dishonest. Until known to the contrary, however, it may be assumed that the Contractor will take pride in his work and will endeavor to give satisfaction, particularly if he can at the same time make a fair and reasonable profit. Natural dishonesty cannot well be eliminated except by experience and refusal to let a contract to any contractor who has already proved dishonest. It is exceedingly difficult to secure good work if it is not profitable to the Contractor. A contract should only be let when prospects of a reasonable profit are assured. Even then, however, the foreman, through a natural desire to cut expenses for his employer, may resort to evasion of specification requirements, the importance of which he does not appreciate, and efficient inspection will be required to secure a satisfactory job.

SPECIFICATIONS

10. General Scope of Specifications. In addition to other sections specifications are frequently printed under such headings as Definition of Terms, General Provisions, Construction Details, and Material Requirements. Under one of these headings, usually "General Provisions," certain stipulations, commonly made, are dealt with in the follow-

ing paragraphs. If these details are lacking the Inspector should request specific instruction from the Engineer regarding all which may be of importance in the work to which he is assigned.

11. Basis of Measurement and Payment. In a given contract payment is, of course, made both for work performed and materials furnished. The basis for measurement, however, may vary. Some items may require bids on the quantity of acceptable material delivered on the work and other items may be on the quantity of work and material in place. In either case it should be made possible for the Inspector to check quantities with considerable accuracy. For materials delivered on the job, bills of lading, measurements of the capacity of containers and direct weights may all be utilized. For work in place, measurements of surface and depth or of volume may be made. If surface measure is to be used the method of taking such measurement should be clearly stated and understood. Thus it may be specified that as a basis for payment the surface of a roadway shall be measured horizontally (§358). In the case of heavy grades this method may show materially less yardage than though the actual surface of the road was measured, as the horizontal length of the road shown on the plans then represents the base of a triangle while the actual length is its hypotenuse. The following stipulation is cited as an example of an ordinarily satisfactory basis of measurement. "All linear surface measurements of work done will be made along the center line of actual surface of the roadway and not horizontally, and the area paid for shall be only the actual area covered by the entire surfacing or paving material wthin the lines designated or given, except that no deduction will be made for fixtures in the roadway or street with an area of 9 square feet or less."

12. Coöperation of Contractor on Inspection. In order that the Inspector may not be hampered in the performance

of his duties, specifications should provide that if requested, the Contractor shall furnish the Engineer or his representative with bills of lading or correct copies thereof of shipments of all materials used and shall furnish every reasonable facility for ascertaining the quantity of material received and used as well as its source. It should also be stipulated that when practicable stored materials shall be so located as to facilitate prompt inspection, and that when tests are made at places other than the Laboratory the Contractor shall furnish every facility necessary for the verification of all scales, measures and other devices which he operates.

13. Inspection Details. Specifications should inform the Contractor that all materials proposed to be used may be inspected at any time during the progress of their preparation and use. They should also state that if after trial it is found that sources of supply, which have been approved upon samples previously examined, do not furnish a product within the specification requirements, the Contractor shall furnish approved material from another source. In addition it should be stipulated that after approval, any material which has become mixed with or coated by dirt or other foreign material shall not be used on the work, and that all rejected material shall be promptly removed from the site of work.

14. Removal and Replacement of Work. Inspection of completed work in which it is deemed necessary to cut out or remove sections of the pavement should be specifically cared for in the specifications so that there will be no misapprehension on the part of the Contractor with consequent dispute. It should be stipulated that if the Engineer requests it, the Contractor, at any time before acceptance of the work, shall remove or uncover such portions as may be directed, and that after examination the Contractor shall restore such portions of the work to the standard required by the specifications. Should the work thus exposed or examined prove acceptable, the uncovering or removing

and replacing should be paid for as extra work on a basis clearly stated in the specifications, but should the work so exposed or examined prove unacceptable, the uncovering or removing and the replacing or making good of the parts removed should be at the Contractor's expense.

CHAPTER II

BROKEN STONE

ROCK

15. Occurrence. Rock occurs most commonly in massive formation such as ledges or beds of interlocking mineral constituents of a crystalline nature. Certain deposits are, however, of an amorphous or noncrystalline nature and possess a smooth or glassy texture. Rock also occurs as field stone in the form of bowlders which have usually been transported and deposited by glacial action. Individual rock deposits are not always uniform in composition, appearance or physical properties, and this fact should be borne in mind by the Inspector, particularly when a source of supply has been approved or is subject to approval upon the results of tests of samples submitted. Strata or dikes of different rock families may even occur in the same deposit. Numerous varieties of rock are found in certain sections of the country while other sections are either devoid of rock or contain a limited number of varieties. As it is the most extensively used of all road materials and its transportation is expensive, local occurrence largely governs specifications for characteristics of rock to be used in highway construction.

16. Classification. Rocks are most accurately classified according to origin, method of formation, structure and mineral composition. There are three general classes of road-building rock which are subdivided into types and families as shown in the following Table:*

* E. C. E. Lord, U.S. Dept. Agri. Bul. No. 348.

General Classification of Rocks

Class	Type	Family
I. Igneous	1. Intrusive (plutonic)	a. Granite. b. Syenite. c. Diorite. d. Gabbro. e. Peridotite.
	2. Extrusive (volcanic)	a. Rhyolite. b. Trachyte. c. Andesite. d. Basalt and diabase.
II. Sedimentary or Aqueous	1. Calcareous	a. Limestone. b. Dolomite.
	2. Siliceous	a. Shale. b. Sandstone. c. Chert (flint).
III. Metamorphic	1. Foliated	a. Gneiss. b. Schist. c. Amphibolite.
	2. Nonfoliated	a. Slate. b. Quartzite. c. Eclogite. d. Marble.

Igneous rocks have been formed either below or at the surface of the earth by crystallization or solidification from a molten condition. Sedimentary or aqueous rocks have been formed by water deposition and compression. Metamorphic rocks have been formed from either igneous or sedimentary rocks through pressure, heat or chemical action which results in an alteration of the original rock structure or mineral composition. Alternation in structure, to the extent of producing cleavage planes, which can usually be distinguished by visual inspection, produces the foliated type. For ordinary purposes the Inspector may consider road-building rock under the following five groups, without reference to all of the families shown in the Table:

(*a*) Trap Rock (including Andesite, Basalt, Diabase, Diorite, Gabbro and Rhyolite).
(*b*) Granite and Gneiss.
(*c*) Limestone (including Limestone, Dolomite and Marble).
(*d*) Sandstone and Quartzite.
(*e*) Chert.

Schist, shale and slate are highly laminated rocks that tend to break into flat plates not suitable for road-building purposes, except sometimes as a filling for sub-base or foundation. The other families not covered in the five groups enumerated are rare from the standpoint of highway work.

17. Manufacture of Broken Stone. (*a*) Before rock is suitable for use in highway work it must be reduced to fragments of proper size. Except in the case of field stones this first involves quarrying. There are two general types of quarries,— the permanent, which is usually a commercial quarry, the general character of product being well known, and the temporary quarry which is often opened and worked by the Contractor to supply work for a single contract. In the latter cases the highway inspector may be required to sample the deposit before the quarry is opened (§ 39). After the rock is blasted and mauled or broken to proper size, it is passed through a crusher, where it is further reduced, after which it is screened into various grades or sizes demanded by the trade.

(*b*) The most important part of the equipment of the crushing plant, insofar as size or grading of the output is concerned, is the screen. Various types of screens and methods of screening are used, all of which together with the type and setting of the crusher influence the quantity and grading of the various size products manufactured. The most common type is the single revolving screen composed of four connected cylindrical metal sections, each section carrying circular perforations of a different diameter

from those of other sections. A dust jacket or section of shorter length but larger diameter, with small perforations or mesh openings, is frequently placed around the regular section containing the smallest perforations. Broken stone from the crusher is passed into this end of the revolving screen and fragments too large to pass the largest perforations are discharged from the other end to be recrushed. The product passing each section is discharged by suitable means into bins provided for the various sizes. Another type of revolving screen is composed of a set of two or more concentric cylindrical sections carrying perforations of different diameter. Bar or grid, and shaking or pulsating screens are less commonly used. In large quarries batteries of screens may be employed, sometimes with small crushers placed between to crush the tailings before they are passed over the next screen.

(*c*) Because a commercial broken-stone product has passed a screen with a given size opening and has been retained on a screen with a smaller known opening, it does not follow that the grading or even the average size of the product is at all constant. There are many other factors which may cause great variation in grading and average size, such as character of the rock, setting of crusher, moist or dry condition of the crusher output, rate of feeding into the screen, inclination and rate of revolution of the screen, and the length of its sections. These facts must be borne in mind by the Inspector when determining whether or not a product meets specification requirements for size (§ 18).

PHYSICAL PROPERTIES

18. Specification Requirements. (*a*) Specifications for broken stone may require a given group or rock family to be used, or may eliminate by name certain kinds of rock and allow all others which possess satisfactory physical characteristics. They frequently eliminate weathered or

disintegrated stone. It is therefore advisable for the Inspector to be able to identify the most important groups by visual inspection or simple field test. In addition, specifications may eliminate certain kinds of rock or certain products by requiring that they be free from thin or elongated pieces.

(*b*) Physical properties most commonly covered by specifications are resistance to abrasion, usually expressed as maximum per cent of wear or minimum French coefficient of wear, and minimum toughness. A minimum hardness coefficient and a minimum cementing value are less frequently specified. Determinations of these values are a matter of laboratory test which the Inspector is not expected to make.

(*c*) The size or grading of broken-stone products may be specified in a number of ways only one of which, however, that based upon the results of screen tests, constitutes an accurate description. A certain commercial grade such as No. 3 may be required; the allowable maximum or maximum and minimum dimensions of individual fragments in the product may be stated; the size rings through which a product must pass and be retained may be given; or a product which actually passes a certain size opening and is retained on a smaller opening in a commercial screen may be specified. All such specifications are faulty in the fact that they do not accurately describe the desired product or else do not make it possible for the Inspector to intelligently pass upon its acceptability. A far better method is to specify a product which will give results within stated limits when subjected to screen analysis or test which the Inspector himself may make (§ 371).

19. Important Rock-forming Minerals. (*a*) In order to identify the principal road-building rocks with some degree of accuracy, the Inspector should be able to at least distinguish between the most common rock-forming minerals. This may often be done with the unaided eye, although

the use of a small magnifying glass will be found helpful, particularly in the case of fine-grained rock. Moistening a freshly broken rock surface will frequently aid in the matter of identification.

(*b*) *Quartz* is an extremely hard mineral occurring in the rock sample in crystals of irregular or rounded shape. It is identified by its almost colorless transparency and vitreous or glassy luster. When present in large quantities and firmly held in the rock structure, it imparts to the rock great hardness and high resistance to wear.

(*c*) *Feldspars*, of which there are numerous varieties, are hard brittle minerals occurring as tabular or lath-shaped crystals. They exhibit a variety of color and are characterized by perfect cleavage along planes almost at right angles to each other. They may usually be identified by the pearly luster of these cleavage faces. Rock which contains large quantities of feldspar tends to break into cubical fragments. If the feldspar crystals are small, hardness and toughness are imparted to the rock; if large, the property of toughness becomes less.

(*d*) Augite and Hornblende occur as elongated crystals running in shade from green to black. When present in considerable amount they impart to the rock a peculiar and well-defined interlocking structure which results in high toughness.

(*e*) Mica, both white (Muscovite) and black (Biotite), occurs in thin glistening plates or flakes which may be easily scratched with a knife. It possesses a highly laminated structure and when present in large amounts is largely responsible for the foliated structure of metamorphic rocks, which tend to break into flat fragments.

(*f*) Rock glass, which occurs in certain igneous rock, has no crystalline form but occurs as a dark vitreous magma filling interstices between the mineral crystals. It is very brittle and when present in appreciable quantity tends to lower the toughness of a rock.

(*g*) Calcite and Dolomite are relatively soft carbonate minerals which may readily be scratched with a knife. They may exhibit a variety of colors due to impurities but usually run from white to dark gray. Calcite may be distinguished by its free effervescence when treated with cold dilute hydrochloric acid, while dolomite effervesces only when treated with the concentrated acid. They usually impart cementitiousness to rocks in which they occur.

20. Trap Rock. The name trap is commonly applied to all dense, fine-grained, igneous rock running from gray to black in color. These rocks invariably contain fine crystals of feldspar, usually averaging between 20 and 60 per cent in volume. Most varieties carry a high percentage of either augite or hornblende, or both, and sometimes chlorite, a dark green mineral, is present in considerable amount. Quartz may either be absent, or present to the extent of over 30 per cent, and the same is true of rock glass. Mica is either absent, or present in the black variety to only a limited extent. When crushed, trap tends to break into cubical fragments. It usually possesses high toughness, hardness, and resistance to abrasion. It averages close to 2.9 specific gravity, although individual samples sometimes run as low as 2.7 and as high as 3.2

21. Granite and Gneiss. Granite and its metamorphic brother Gneiss are typical rather coarse-grained rocks composed essentially of quartz and feldspar with a less amount of mica. Augite and hornblende may be absent, but the latter is not an uncommon constituent of both. They exhibit a variety of colors, but are usually gray or pink. The fracture of granite is rough and more rectangular than that of trap. Gneiss is distinguished from granite by its foliated or stratified structure which tends to cause it to break into rather flat fragments. Both granite and gneiss are characterized by low toughness and high hardness with resistance to abrasion somewhat lower than for trap rock. Their

specific gravity averages close to 2.7 and is seldom less than 2.6 nor more than 2.8.

22. Limestone. Limestone, including dolomite and marble, is usually a crystalline rock varying in color from almost pure white to dark grayish black. The very soft varieties are, however, of a chalky nature. It consists essentially of calcite, dolomite, or both, with usually a small amount of quartz. Its free effervescence when treated with strong hydrochloric acid and the fact that it can be scratched with a knife serve to identify it. Limestone runs usually much lower in hardness, toughness, and resistance to wear than do the traps, and granites, and is about the same as gneisses. Its cementing value is, however, good. The specific gravity of limestone averages about 2.7 and is seldom less than 2.6 or higher than 2.9. Marble averages somewhat higher than 2.7 specific gravity.

23. Sandstone and Quartzite. Sandstone and its metamorphosed equivalent, quartzite, are composed of gains of sand bound together by a cementing material. They, therefore, consist chiefly of quartz, although other minerals such as feldspar and mica are usually present in appreciable quantity. They vary from fine to coarse grain and exhibit a number of colors, the most common shades being gray, white to buff, brown, and red. The grains of sandstones may be loosely bound or strongly bound together and their physical properties, therefore, vary widely. Quartzite differs from sandstone mainly in its greater hardness and toughness, density and crystalline character. Its fracture shows a more vitreous luster and usually passes through the individual sand grains instead of between them, as in the case of sandstone. The specific gravity of sandstone varies between wide limits, but usually lies between 2.4 and 2.8 with an average of a little more than 2.6. The specific gravity of quartzite usually lies between 2.6 and 2.8.

24. Chert. Chert, also known as flint, and, in the form of tailings from zinc and other ores, as chats, is a hard non-

crystalline or amorphous rock which breaks with a conchoidal fracture. It varies in color from light gray to black. Owing to its tendency to fracture along lines which have developed as shrinkage cracks in the rock structure, it frequently shows a low resistance to abrasion and is extremely difficult to test for toughness. The cementing value of fine chert is usually low, but some highly weathered deposits develop good cementing value, especially if a high binding clay is associated with it. Its specific gravity ordinarily lies between 2.4 and 2.65.

25. Fieldstone and Conglomerates. Field stones are apt to possess extremely variable physical properties as they are composed of various types of rock which have been deposited by glacial action or by surface weathering. Conglomerates and breccias are likely to show a similar variation in properties. The former are rounded fragments of rock cemented together in the rock mass and the latter are angular fragments similarly held together. Pudding stone is a name given to certain conglomerates.

26. Schist, Shale and Slate. Schists, shales and slates possess a highly laminated or stratified structure and tend to break into flat plates. They are seldom suitable for road-building purposes except perhaps as a filling for sub-foundations. They vary greatly in nearly all of their physical properties.

27. Relative Properties of Important Rocks. (*a*) The relative physical properties of the most important road-building rock are diagrammatically shown in Figs. 1 to 3. These diagrams represent the results of a large number of tests made in the laboratories of the U. S. Bureau of Public Roads.

(*b*) In Fig. 1 is shown the percentage of total samples tested, giving results at or above various values for the French coefficient of wear, for the four principal groups of road-building rock. It will be noted that 75 per cent of all samples give a French coefficient of wear

above 7 and that 50 per cent give a coefficient above 9. The curve for trap shows the highest values, and it is evident that in a trap rock country specification requirements may consistently be made more rigid than where other types predominate.

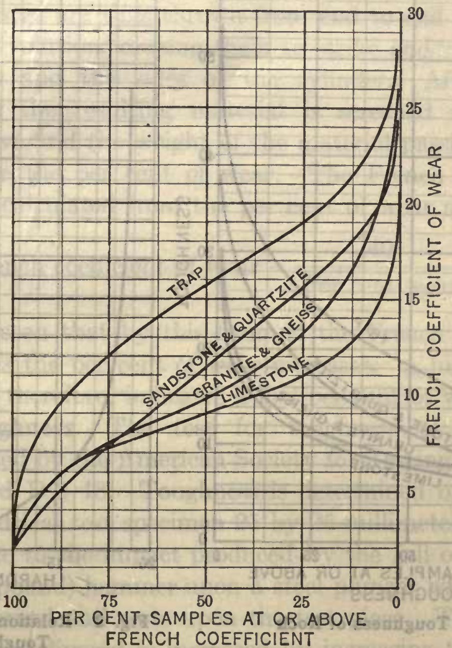

Fig. 1 Resistance of Rock to Abrasion or Wear

(*c*) Fig. 2 shows toughness values for the four rock groups in the same manner as the French coefficient of wear is shown in Fig. 1. In general it will be noted that the relative positions of the curves in both figures are similar, although the limestones and granites and gneisses run closer together. Over fifty per cent of all samples show a toughness of 8 or more.

(*d*) A fairly well-defined relation between the properties of hardness and toughness has been established which is shown by Fig. 3 in which coefficients for hardness for all types of rock are plotted against their respective toughness.

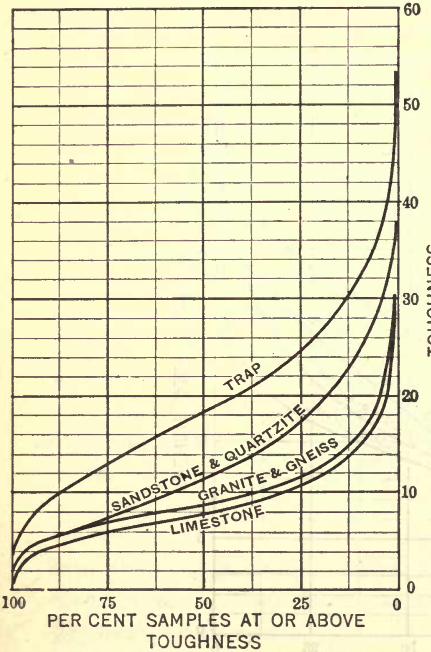

Fig. 2 Toughness of Rock

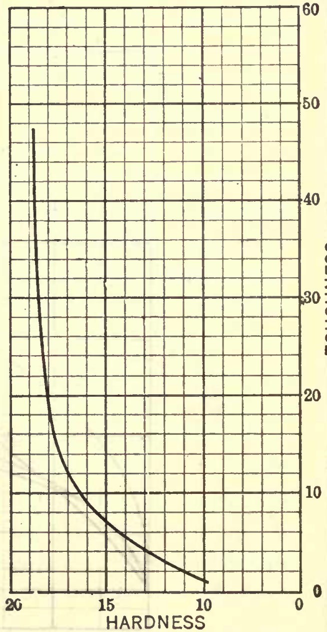

Fig. 3 Relation of Hardness to Toughness

Thus it is seen that a rock having a toughness of 8 will usually show a coefficient of hardness of about 15.5. Because of this general relation, it is frequently unnecessary to specify both toughness and hardness limits for road-building rock.

ROCK TESTS

28. Resistance to Abrasion or Wear. This test, sometimes termed the Deval Abrasion Test, has been adopted

by the American Society for Testing Materials as Standard D 2–08: Five kilograms (11 pounds) of freshly broken rock between 2 and $2\frac{1}{2}$ inches in size is tested in a special form of cylinder so mounted on a frame that the axis of rotation of the cylinder is inclined at an angle of 30° with the axis of the cylinder itself. The fragments of rock forming the charge are thus thrown from end to end twice during each revolution, causing them to strike and rub against each other and the sides of the cylinder. After 10,000 revolutions the resulting material is screened through a $\frac{1}{16}$-inch sieve and the weight of the material passing is used to calculate the per cent of wear. The French coefficient of wear is calculated from the per cent of wear as folllows:

$$\text{French coefficient of wear} = \frac{40}{\text{Per cent wear}}.$$

It will be seen that by this formula the French coefficient decreases as the per cent of wear increases. A high French coefficient, therefore, indicates a low per cent of wear.

29. Toughness. The test for toughness of rock has been adopted by the American Society for Testing Materials as Standard D 3–18. Toughness is determined by subjecting a cylindrical test specimen 25 by 25 millimeters (1 by 1 inch) in size to the impact produced by the fall of a 2-kilogram (4.4 pound) hammer upon a steel plunger whose lower end is spherical and rests upon the test piece. The energy of the blow delivered is increased by increasing the height of fall of the hammer 1 centimeter (0.39 inch) after each blow. The height of blow in centimeters at failure of the specimen is called the toughness.

30. Hardness. Hardness is determined by subjecting a cylindrical rock core 25 millimeters (1 inch) in diameter, drilled from the specimen to be examined, to the abrasive action of quartz sand fed upon a revolving steel disk during 1000 revolutions. The end of the specimen is worn away in inverse ratio to its hardness and the amount of loss is

expressed in the form of a coefficient according to the following formula in which w is the loss in weight.

$$\text{Coefficient of hardness} = 20 - \frac{w}{3}.$$

From this formula it is seen that the higher the coefficient the harder is the rock.

31. Cementing Value. To determine the binding power, or cementing value, as it is usually called, 500 grams (1.1 pounds) of the material to be tested is crushed to pea size and ground with water in a ball mill until it has the consistency of a stiff dough. It is then moulded into cylindrical briquettes 25 by 25 millimeters (1 by 1 inch) in size, which, after thorough drying, are tested to destruction in a special form of impact machine. A 1-kilogram (2.2-pound) hammer falls through a constant height of 1 centimeter (0.39 inch) upon an intervening plunger, which in turn rests upon the test piece. By means of a suitable arrangement a graphic record of the number of blows required to destroy the specimen is obtained. The number of blows producing failure is called the cementing value of the material.

32. Size or Grading. The size or grading of broken stone products is ascertained by making a mechanical screen analysis. This may be done by the Inspector (§ 371), the Laboratory, or both. A dry sample of the product weighing not less than fifty times the weight of the largest stone present is passed through screens having circular openings, as are required or called for by the specifications. Starting with the screen with largest openings, the percentage by weight retained on each screen and the percentage passing the screen with smallest openings is recorded.

33. Specific Gravity, Weight per Cubic Foot, Absorption. (*a*) There are a number of methods for making this determination. The American Society for Testing Materials has adopted standard test D 30–18 for determination of apparent specific gravity of coarse aggregates, which may be briefly

described as follows: A 1000-gram sample composed of suitably sized fragments is dried and weighed. It is then immersed in water for 24 hours and again weighed. Its weight under water suspended in a wire basket is next ascertained. The specific gravity of the sample is then calculated by means of the following formula in which A is the weight of the dry sample, B the weight of the saturated sample in air, and C its weight in water,

$$\text{Sp. Gr.} = \frac{A}{B - C}.$$

A similar method may be used by the Inspector (§ 376) in the field for obtaining a rough determination.

(*b*) The absorption of the rock is obtained on a percentage basis as follows:

$$\text{Per cent absorption} = \frac{100(B - A)}{A}.$$

(*c*) Sometimes the results of the specific gravity and absorption tests are reported upon the basis of pounds per cubic foot of solid rock. In this case the weight per cubic foot equals the specific gravity multiplied by 62.4. The absorption in pounds per cubic foot equals the per cent of absorption multiplied by the weight per cubic foot.

34. Determination of Voids. Voids in a broken stone aggregate after compaction by settlement may be ascertained by measuring the volume of water required to fill the interstices of a known volume of compacted aggregate. The per cent of voids is calculated by dividing this volume of water by the apparent volume of the aggregate. If the specific gravity of the aggregate is known, the per cent of voids may also be determined by dividing the weight of a given volume of the aggregate by the calculated weight of the same volume of the solid rock and subtracting this result from 1.00 (§ 377).

MEASUREMENT

35. Weight Basis. Broken stone is most frequently purchased and, therefore, measured by weight. While this is usually a satisfactory basis there are two factors which the Inspector should bear in mind. One is that the weight of broken stone is not necessarily a constant, and the other that considerable difference in volume may be represented by the same weight. In connection with the former, the weight of perfectly dry rock may be increased by absorption of water amounting in some limestones to as high as 13 per cent. To this may be added water which is mechanically held on the surface of the individual fragments of the aggregate which, as determined in the laboratory, may amount to over 1 per cent for very wet rock. Freight weights are usually accepted as a basis for payment if shipment is made by rail, but in all cases it should be understood that original weights are to be on the basis of air-dry products. The relation of volume to weight is considered in paragraphs 36 and 37.

36. Volume Basis. While the volume of broken stone is perhaps the most satisfactory basis for estimating the amount of road or pavement to be or which has been constructed, the fact that the volume of an aggregate is not a constant makes it an unsatisfactory basis for purchase. Thus a given weight of rock when first loaded upon a freight car will occupy considerably more space than when received at its destination, due to settlement or reduction in voids in transit. If purchased upon a volume basis the place and the conditions under which measurement is made should be clearly understood in advance. Under the same conditions the relation of weight to volume of a given broken-stone product is a constant, so that a cubic yard may be assigned a definite weight. When, however, a variety of rocks is considered, it is evident that the specific gravity of the rock will considerably affect its weight per cubic yard.

Thus, if a cubic yard of broken stone with a specific gravity of 2.6 weighs 2600 pounds, a cubic yard of the same grade of product in the same state of compaction for a rock of 3.0 specific gravity would be 3000 pounds per cubic yard, thus making a difference of 400 pounds per cubic yard. Where rocks of such a range of specific gravity are allowed to be used in a given contract it is evident that the weight of rock required may vary appreciably and that the actual weight used is no true measure of work done unless the specific gravity of the product is known. To illustrate: if a given weight of broken stone of 3.0 specific gravity will build 13 miles of road, the same weight of broken stone of 2.6 specific gravity will build 15 miles of road. Such a difference is worth some consideration if the stone is purchased upon a weight basis.

37. Voids. (*a*) It has been stated that the volume of broken stone is not a constant because of settlement or reduction in voids. In any broken-stone product the per cent of voids will depend principally upon two factors: the grading of the aggregate and its degree of compaction. In general, the percentage of voids is greatest when the fragments are of uniform size and have not been closely packed by settlement or pressure. They are least when the fragments are so graded that for a given volume of the larger sized fragments there are just sufficient smaller particles to fill the interstices, and when all of the particles are brought into the most intimate contact possible through compaction. For the average commercial broken-stone product of fairly uniform size numerous tests have shown that when loose and uncompacted by travel, also in thin layers, the voids are approximately 50 per cent; under light compaction or travel and in thick masses, they are about 45 per cent; and when compacted by heavy travel, shaking or high drop they are 40 per cent. Forty per cent voids represent about the maximum compaction without rolling. This makes a convenient basis for figuring pounds per cubic yard which is

then for all practical purposes 2000 times the specific gravity of the rock. Thus a rock of 2.7 specific gravity with 40.5 per cent voids will weigh 2700 pounds per cubic yard.

(*b*) For the purpose of estimating quantities needed or amount used of a given commercial size, the following percentage of voids may be assumed:

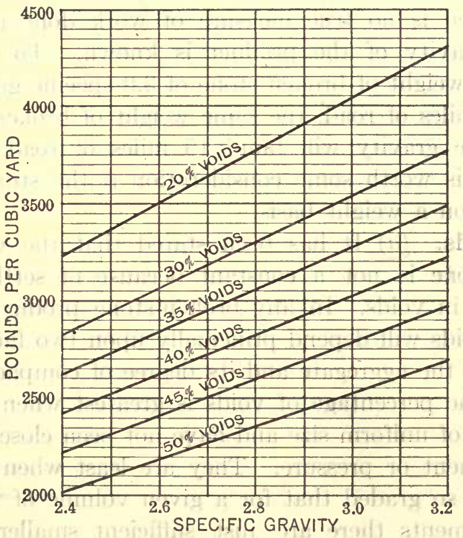

Fig. 4 Weight of Broken Stone

Loose piles or very thin layers	50 per cent
Loose spread water bound macadam	45 " "
Coarse aggregate for Portland Cement Concrete	45 " "
Coarse aggregate for Graded Bituminous Concrete compacted	40 " "
Crusher run, loose, without segregation	35 " "
Rolled broken stone	30 " "
Crusher run, compacted	20 " "

The approximate weight per cubic yard and number of cubic yards per 100 tons for broken stone of different

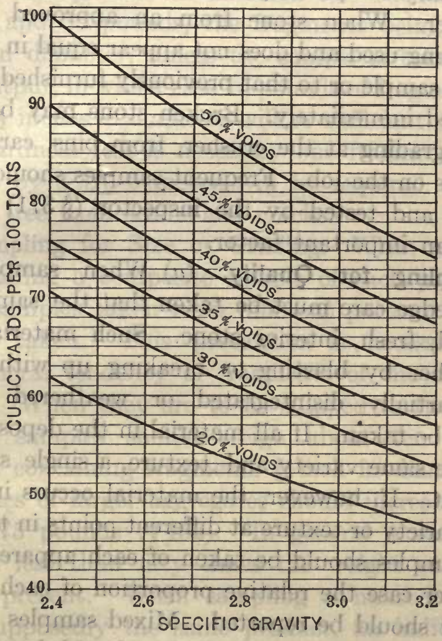

Fig. 5 Volume of Broken Stone

specific gravities and the various percentages of voids above mentioned are shown in Figures 4 and 5.

SAMPLING

38. Time and Place of Sampling. Samples of rock or broken stone may be taken at any time before or during its use. When the specifications require physical properties which must be determined by laboratory test, a preliminary sample should be taken from each proposed source of supply at least two weeks before final acceptance. However, in

the case of well-known sources of supply, from which the material has been tested and approved within one year, the preliminary sample may be omitted at the discretion of the Engineer. When stone from an approved source of supply is being used and does not appear equal in quality to the original sample or to that previously furnished, it should be resampled immediately. Broken stone may be sampled for size or grading at the crusher, from bins, cars, or from storage piles on the job. Frequent samples should be taken on the job and tested by the inspector (§ 371) when the grading is an important factor.

39. Sampling for Quality. (*a*) When sampling from quarry or ledge care must be taken that the sample represents sound, fresh, interior stone. Such material may be secured either by blasting or breaking up with a sledge. Rotten, partially disintegrated or weathered specimens should not be taken. If all material in the deposit is essentially of the same variety and texture, a single sample will be sufficient. If, however, the material occurs in layers or differs in variety or texture at different points in the deposit, separate samples should be taken of each apparent variety. In the latter case the relative proportion of each variety in the deposit should be reported. Mixed samples or samples representing two or more varieties should be taken only when especially directed, in which case the relative proportion of the different varieties in the sample should be made as nearly as possible the same as the proportions in which they occur in the deposit. It is advisable for the Inspector to retain a small specimen representative of the rock sampled to be used as a guide in inspecting shipments of the material if approved. In the case of field stone, when two or more varieties of great difference in quality or texture are observed, separate samples should be taken of each and the percentage of each kind, together with the relative amount of disintegrated or badly weathered rock present, should be reported. It is also advisable to report the relative amount

of small stone which might be expected to pass through the crusher without breaking.

(*b*) Each sample for the abrasion test should weigh between 25 and 35 pounds, the fragments being two inches or more in diameter, unless the sample is taken from the crusher output, in which case 15 pounds of fragments averaging 2 to $2\frac{1}{2}$ inches in diameter will be sufficient. If a toughness or hardness test is necessary one fragment measuring at least 3 by 4 by 6 inches will be required. This piece should be free from seams and cracks.

40. Sampling for Size or Grading. When sampling for size or grading a composite sample of each product, composed of samples taken from different parts of the supply, should be taken. This precaution is necessary because of the general tendency of fragments of the same size to segregate. When they are to be shipped to the laboratory composite samples should weigh about ten pounds for aggregates containing fragments $\frac{3}{4}$ inch in diameter or less and samples of larger aggregates should increase in size up to 60 or 75 pounds (§ 153). In general a sample should weigh not less than fifty times the weight of the largest fragment present. When sampling a number of cars or piles of supposedly the same product, an individual composite sample should be taken from each car or pile the size or grading of which is apparently different from the others.

CHAPTER III

GRAVEL, SAND AND CLAY

NATURAL ROCK PRODUCTS

41. Occurrence. Under prolonged action of the elements massive rock disintegrates and frequently suffers decomposition and so produces soils. Thus, frost action may result in the splitting or breaking up of rock masses while the action of ground waters may produce chemical changes in the constituent minerals, resulting in alteration of the rock structure. Fragments of rock and decomposition products have in certain cases remained at or near their place of formation and, in other cases, have been transported for long distances by water, wind or glacial action. When rock fragments remain at or near their place of formation they become weathered or rotten under atmospheric influences and are usually unsuitable for highway construction. If transported the surface of individual fragments usually becomes polished by abrasive action and often rounded, while soft decomposition products are removed. As they are eventually deposited by the force of gravity, fragments of approximately the same size and weight tend to separate or segregate from fragments of different size or weight. While such segregation is seldom complete, deposits frequently show a preponderance of fragments within certain ranges of size which are used as a basis for classification. These deposits may occur locally as beds of lakes or rivers, or in banks or beds forming a part of the earth's surface.

42. Classification. The fact that the greatest variety of different size fragments in all combinations of relative

proportion occurs in natural soil deposits makes the matter of their classification extremely difficult, and no standard of classification has been generally adopted by highway engineers. Any specification calling for gravel or sand in particular should, therefore, define the terms for that specification. Where specifications are indefinite the following class limits based upon field or laboratory test may, however, prove of service to the Inspector:

Boulders. Fragments with a maximum diameter of 6 inches or more.

Gravel. All fragments which will be retained on a $\frac{1}{4}$-inch screen.

Sand. All fragments which will pass a $\frac{1}{4}$-inch screen and be retained on a 200-mesh sieve.

Silt. All particles which will pass a 200-mesh sieve and will not be removed by elutriation.

Clay. All inorganic matter which will be removed by elutriation.

While the above limits will serve to distinguish between the constituents of a natural deposit, they do not classify the combinations commonly found. Such classification is taken up under separate headings for gravel, sand, and clay.

GRAVEL

43. Types of Gravel. (*a*) Pebbles of gravel in a given deposit may be and most frequently are composed of a variety of rocks, although a given rock family or group usually predominates. The name of the predominating rock, if there be one, is commonly assigned to the product, so that the terms *trap gravel*, *granite gravel*, *limestone gravel*, *quartzite* or *quartz gravel*, and *sandstone gravel* are not infrequently used. The general nature of the deposit is also used to designate gravel, the most common terms being glacial gravel, bank or pit gravel, river gravel, and lake gravel.

(*b*) In addition, gravels or gravel deposits are roughly classified by the proportion and nature of other constituents which may be present. The most important types from this standpoint are the sand or sandy gravel, the sand-clay gravel, and the clay gravel. In general gravel deposits may be considered as deposits containing less than fifty per cent of boulders or cobbles and a percentage of gravel greater than the per cent of all other constituents combined. Sandy gravel is gravel in which the proportion of combined sand and silt to clay is greater than 10: 1. Clay gravel is that in which the proportion of combined sand and silt to clay is less than 3: 2. And sand-clay gravel lies between the two last named varieties. Gravel in which the pebbles mainly range from $\frac{1}{2}$ to $\frac{1}{4}$ inch in diameter is sometimes known as pea gravel. Large gravel pebbles and small rounded boulders are sometimes called cobbles.

44. Production. As dug from a bank or pit, or dredged from the bed of a river or lake, gravel is frequently unsuited for direct use. To meet the requirements of a given specification it may have to be screened to remove undesirably large fragments and perhaps sand and other fine material. It is sometimes washed for the latter purpose. It may also be necessary to separate it into certain ranges of size or grading. When this is the case and the deposit contains an appreciable proportion of pebbles larger than the maximum required size, a complete crushing and screening plant may be employed similar to that used in the manufacture of broken stone (§ 17).

45. Physical Properties. (*a*) Specifications for gravel sometimes specify the type of deposit from which it is to be obtained, the soundness of its particles, and freedom from clay, loam, dirt and coatings. The maximum size of individual pebbles is almost invariably specified and in many cases size or grading of each gravel product to be used is covered. Less frequently its resistance to abrasion and its cementing value or that of its finer constituents are specified.

(*b*) From the nature of their origin, the physical properties of gravels vary widely. In general the toughness and hardness of gravel will approximate that of its predominating rock, but it is impracticable to use the tests for these properties as applied to rock. Durability under traffic conditions is the important thing to consider and, in general, trap, quartz and chert gravels are the most durable. If cementing value is required, a certain amount of clay binder is desirable except in the case of a limestone gravel or one containing an appreciable amount of limestone. Sandstone gravels because of their smooth or polished surfaces may appear to be perfectly sound and highly resistant to abrasion. Frequently, however, if the surface is broken, inferior quality or unsound rock will be exposed. Such gravels rapidly break down into sand under traffic, owing to their lack of toughness.

(*c*) The size of grading of gravel may be specified as in the case of broken stone (§ 18c). The most satisfactory method is that based upon screen, or screen and sieve tests, which in many cases may be made by the Inspector (§ 371). Owing to the rounded nature of most gravel particles, no interlocking occurs in a compacted mass as in the case of broken stone. Glacial gravels differ from others in the fact that the individual pebbles are more or less angular. Crushed gravel resembles broken stone in its ability to interlock in proportion to the relative amount of crusher-broken fragments which it contains. When gravel is composed largely of rounded particles mechanical stability in a road structure is obtained only by the presence or use of a fine aggregate filler and a cementing medium. The specific gravity and voids in a gravel product will, of course, depend upon the relative proportion of different types of rock present and the grading of the aggregate which is extremely variable. The voids in gravel which is screened into commercial sizes and the reduction of voids due to compaction is approximately the same as for broken stone of the same size (§ 37).

SAND

46. Types of Sand. (*a*) As a rule sand is of much more uniform composition than gravel. It represents the survival of the fittest of all the common rock forming minerals which is chiefly quartz. The other minerals, which are largely silicates and carbonates, are as a rule decomposed during the reduction of rock to the size of sand grains so that by far the largest proportion of the final product consists of quartz fragments which may be smooth and round or sharp and angular. There are some exceptions to this rule, however, particularly where the sand constitutes a portion of a limestone gravel, in which case it is also composed mainly of limestone particles. Like gravel, the general nature of the deposit may be used to designate sand, the most common varieties being glacial sand, bank sand, dune sand, river sand, lake sand and beach sand.

(*b*) Sands are further classified by the proportion of other constituents which are present. In general, sand deposits may be considered as deposits containing a greater percentage of sand than the combined percentage of all other constituents. A gravelly sand is one in which an appreciable proportion of gravel is present. A sand-clay is a mixture of sand and clay in which the proportion of sand and silt to clay lies between 10: 1 and 3: 2. A loamy sand is one containing silt, clay and decomposed vegetable matter or humus. To this type, occurring in fields which have been cultivated, the name top soil has been given. Sand which is composed principally of particles which will be retained on a 10-mesh sieve is sometimes known as torpedo sand, or gravel grit if the preponderating particles average about $\frac{1}{4}$ inch in diameter. Concrete sands are fairly coarse sands, the largest proportion of particles being usually retained on a 50-mesh sieve. Sands for sheet asphalt are well-graded products which will pass a 10-mesh sieve and are practically free from silt and clay. Grouting sands are

usually fine products at least 80 per cent of which will pass a 20-mesh sieve.

47. Production. As excavated or dredged from natural deposits sand may not be directly suited for use and may have to be screened to remove gravel or all particles over a given size. This is frequently done by throwing the sand against a string or wire screen, the inclination of which controls to a considerable extent the maximum size particle which passes. Sands containing undesirable amounts of silt and clay, but otherwise suitable, may have to be washed after removal from the deposit. If clay or organic matter actually coats the sand grains and does not exist mainly as a void filler, washing the sand will seldom produce a satisfactory product. If the grading of the sand is not satisfactory it is sometimes mixed with another selected sand in such proportions as to produce the desired grading. This operation is usually conducted at or near the place where the sand is to be used, as for instance, a paving plant. In some cases it may be necessary to mix clay with the sand or to add a fairly clean sand to one containing more than the desirable percentage of clay. Such mixtures, intended to produce a sand-clay suitable for highway purposes, are prepared in place on the road, one constituent being the natural soil existing at such place.

48. Physical Properties. (*a*) Specifications for sand frequently specify the soundness and durability of the individual grains as well as their freedom from coatings of clay or loam. The general type of grains, whether round or sharp, is sometimes stipulated, together with the absence of dirt and other foreign matter. The grading of the sand is usually covered in some manner, often in considerable detail, and for some types of work the allowable or necessary percentages of gravel, silt or clay are included. The cementing value of the product may also be specified and in rare instances its resistance to abrasion. The tensile strength imparted to Portland cement mortar in which it

is used is quite often included in specifications for sand to be used in concrete construction.

(*b*) Because of its method of formation and usual composition, the durability of sand or its resistance to abrasion is high. In exceptional cases such as limestone sands, resistance to abrasion is a variable quantity which may be determined by test (§ 51). When sand is associated with clay or organic matter, such material may exist merely as a void-filling medium for the clean sand grains or a portion may become firmly attached as a coating. This may be ascertained by means of a magnifying glass or microscope. Coated sands are unsuitable for use when they are to be mixed with hydraulic or bituminous cements, as the coating interferes with the bond which it is desired to secure in such mixtures. The presence of an appreciable amount of organic matter existing either as a coating or void filler is considered injurious if the sand is to be used with hydraulic cement. An appreciable amount of mica is also considered undesirable, particularly if a dense product is required, as the flat plates of this mineral tend to prevent the sand grains from packing together as closely as they otherwise would. The cementing value of a sand will depend almost entirely upon the quantity and character of clay which may be present. Pure quartz sand shows practically no cementing value by test. Limestone or carbonate sands are, however, an exception and may develop good cementing value even if clay is absent.

(*c*) The size or grading of sand is usually specified upon the basis of laboratory screens and sieves, and is frequently a most important consideration in highway construction with relation to density, stability and workability. No matter what its grading or state of compaction, clean dry sand is unstable or readily subject to displacement. Compacted wet or saturated sand may, however, possess considerable stability, depending upon its size and grading. If all of its particles are approximately of the same size, as in

the case of quicksands, it is unstable in either the wet or dry state. The percentage of voids, and, therefore, the weight per unit volume of sand, is largely governed by its grading and moisture content, as well as its degree of compaction. The presence of moisture in particular interferes with compaction to a very material extent and within certain limits its addition to sand will cause swelling or increase

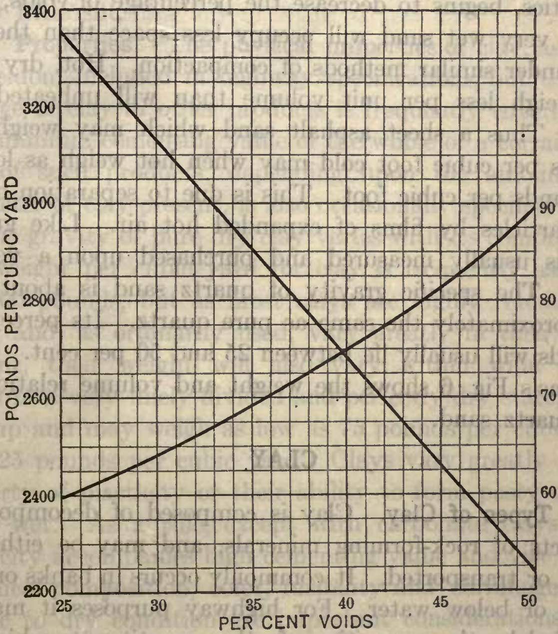

Fig. 6 Weight and Volume Relations for Dry Quartz Sand

in volume. This is due to the fact that in moist sand a film of water coats each particle and by surface tension separates it from the surrounding particles. This effect is so pronounced that with the added weight of water present, moist sand will weigh materially less per cubic yard than the same sand dry. It is most important that the Inspector bear this fact in mind in the measurement of quantities and

proportions. The effect of moisture is a variable depending upon the composition and grading of the sand. Between 3 and 10 per cent of moisture will usually produce the maximum difference which experiments have demonstrated may be as high as 12 per cent voids or over 500 pounds per cubic yard. After the maximum effect of moisture is produced the further presence of water, owing to its lubricating properties, begins to decrease the percentage of voids, until finally very wet sand will occupy less space than the dry sand under similar methods of compaction. Hot, dry sand will weigh less per unit volume than will unheated dry sand. Thus a sheet asphalt sand which may weigh 111 pounds per cubic foot cold may when hot weigh as low as 95 pounds per cubic foot. This is due to separation of the fine particles by films of expanded hot air. Like gravel, sand is usually measured and purchased upon a volume basis. The specific gravity of quartz sand is about 2.65 or approximately the same as pure quartz. Its percentage of voids will usually lie between 25 and 50 per cent. Upon this basis Fig. 6 shows the weight and volume relations of dry quartz sand.

CLAY

49. Types of Clay. Clay is composed of decomposition products of rock-forming minerals, and may be either residual or transported. It commonly occurs in banks or beds above or below water. For highway purposes it may be classified by the proportion of other constituents which are present and, in a general way, by its variations in the properties of plasticity and slaking. In general clay deposits may be considered as deposits containing a greater percentage of clay than the combined percentage of all other constituents. A sandy clay is one in which an appreciable proportion of sand or sand and silt is present. Calcareous clay contains an appreciable percentage of calcium carbonate, and if the percentage of this constituent is relatively

high, the product becomes marl. Gumbo is a type of clay containing a high percentage of decayed vegetable or organic matter and very little sand or silt, while loam is composed of clay and sand mixed with considerable vegetable matter or humus. A lean clay is a non-plastic, rapid slaking clay containing, as a rule, considerable silt, and a fat clay is highly plastic, slow slaking, and contains relatively little silt.

50. Properties. The physical properties of clay, as such, are seldom included in highway specifications, but the percentage of clay in other products is frequently covered and the minimum cementing value of the whole or a certain portion of such products, depending upon the amount and character of clay present, is also occasionally specified. The specific gravity of pure dry clay varies with its composition. The weight per cubic yard for clay is frequently assumed as 2700 pounds, but as most clays are highly retentive of water and, as ordinarily used, vary greatly in their water content, their weight will also vary within wide limits. When in a very finely divided and perfectly dry state, clays fluff up and may weigh as low as 75 pounds per cubic foot or 2025 pounds per cubic yard. Clays vary greatly in the property of plasticity or their ability to form pasty masses when wet. As a rule, except with carbonate clays, high plasticity accompanies high cementing value and vice versa. Chemical composition, color, fusibility and shrinkage from plastic to dry condition are important considerations from the standpoint of paving brick manufacture, but such properties with the exception of shrinkage are not usually a matter of importance to the Inspector

TESTS

51. Resistance to Abrasion or Wear. (*a*) Gravel. No standard method for making an abrasion test for gravel has been generally adopted. When specified, however, a test

devised by A. S. Rea is usually made by first screening the gravel so as to obtain two products, the one passing a 2-inch and retained on a 1-inch screen, the other passing the 1-inch and retained on a $\frac{1}{2}$-inch screen. Twenty-five hundred grams ($5\frac{1}{2}$ lbs.) of each size is then placed in a Deval Abrasion machine together with six cast-iron spheres, each about 1.9 inches in diameter and weighing approximately one pound. The test is made in the same manner as for rock (§ 28) and the amount of material which after test passes a $\frac{1}{16}$-inch sieve is expressed as per cent of wear. When the material has a specific gravity below 2.20 a total weight of 4000 instead of 5000 grams of material is used. Results reported by Rea vary from 3.3 per cent for a hard mixed gravel to 30 per cent wear for a poor sandstone gravel.

(*b*) *Sand.* An abrasion test for sand is less frequently used, but the following method devised by F. L. Roman has been employed by the Illinois State Highway Commission. Five hundred grams (1.1 lb.) of the sand which has been passed through a $\frac{1}{4}$-inch screen and retained on a 50-mesh sieve, and which has been washed free of clay and organic matter, is placed in a Deval Abrasion Machine together with 250 grams (1.05 lbs.) of $\frac{1}{2}$-inch spherical steel shot. The charge is subjected to 200 revolutions at the usual rate for rock (§ 28) after which the per cent of material passing a 100-mesh sieve is reported as the per cent of wear. Under such a test pure quartz sand may show as low as 0.2 and a soft limestone sand as high as 7.6 per cent of wear.

52. Cementing Value. The cementing value of gravel, topsoil, and sand clay is determined in the same manner as for rock (§ 31) except that only that portion of the product which passes a $\frac{1}{2}$-inch screen is tested.

53. Washing and Elutriation Tests. (*a*) The washing test usually precedes the determination of size or grading of which it is really a part. For gravel a dry sample of the material weighing not less than 50 times the weight of the largest size stone present is placed in a shallow pan, covered

with water, and thoroughly agitated for 15 seconds. After 15 seconds' sedimentation the water is poured off through a 200-mesh sieve and the operation repeated until the wash water is approximately clear. The washed material, together with any residue retained on the sieve, is then dried and weighed. The difference between this and the original weight is calculated and reported as per cent removed by washing.

(*b*) For sand approximately 100 grams of the dry material, accurately weighed, is placed in a 500-c.c. (1 pt.) glass beaker about three quarters full of water and agitated in such a manner that no whirling results. After settling for 20 seconds the water is poured off through a 200-mesh sieve and the operation repeated until the wash water is approximately clear. The washed material, together with any residue retained on the sieve, is then dried and weighed. The difference between this and the original weight is calculated and reported as per cent removed by elutriation.

54. Size or Grading. Size or grading tests may be made by the Inspector (§ 371) as well as by the Laboratory. If a washing or elutriation test is required, the residue is passed through such screens and sieves as are required by the specifications and the results expressed on the basis of weight of the original sample. When such preliminary tests are not required, the same weight of dry sample is passed directly through the screens and sieves. The per cent by weight retained on each screen or sieve but passed by the one with next largest openings, together with the per cent passing the screen or sieve with smallest openings, is reported.

55. Washing Test and Grading oi Topsoil and Sand Clay. This test is usually made in the laboratory. A 500-gram sample of the dry material is passed through a 10-mesh sieve and that which is retained is weighed and recorded as coarse material. Fifty grams of the material which passes the sieve is then placed in a wide-mouth bottle with 5 c.c. of dilute ammonia water and 200 c.c. of water. The bottle is stoppered and shaken for 20 minutes, after

which the sample is allowed to settle for 8 minutes and the supernatent liquid poured off. The process is repeated until the supernatent liquid is clear, after which the sample is dried and weighed and the difference in weight recorded as clay. The dried residue is next passed through 20-, 60-, 100-, and 200-mesh sieves, the residue retained on each sieve being weighed and recorded as sand. That portion passing the 200-mesh sieve is also weighed and recorded as silt. All weights are calculated to the percentage of the original sample taken, and reported on that basis under the headings coarse material, sand, silt and clay.

56. Specific Gravity. When little or no material will pass a $\frac{1}{4}$-inch screen, specific gravity is determined in the same manner as for rock (§ 33). In other cases the product is separated into two sizes by means of the $\frac{1}{4}$-inch screen and the specific gravity of each is determined. For fine aggregates, or those passing the $\frac{1}{4}$-inch screen, optional methods of the American Society for Testing Materials, Tentative Standard Test D 55–18 T may be used. In brief this test consists in measuring the volume of liquid displaced in a special measuring flask by a known weight of the material. The weight in grams divided by the displaced volume in cubic centimeters gives the specific gravity of the product.

57. Determination of Voids. The per cent of voids in gravel or sand may be determined in the same manner as for broken stone (§ 34).

58. Mortar Tensile Strength Test for Sand. This test is frequently required of sand to be used in hydraulic cement concrete construction and is preferably made with the same brand of accepted cement proposed for use on the job. Briquettes composed of three parts of the sand, passing a $\frac{1}{4}$-inch laboratory screen, to one part of cement are made in the same manner and of as nearly the same consistency as possible as ordinary standard mortar briquettes which are prepared at the same time for the purpose of comparison. These briquettes are stored and tested at the end of 7 and

28 days in the same manner as the ordinary mortar test for Portland cement (§ 81). The average tensile strength in pounds per square inch for at least three briquettes is compared with that of the standard mortar briquettes, the results being usually expressed as strength ratio on a percentage basis. Thus, if the sand produces a tensile strength the same as the standard mortar, its strength ratio is said to be 100%

SAMPLING

59. Time and Place of Sampling. Samples of gravel and sand products may be taken at any time prior to or during their use. As in the case of rock, when the specifications require physical properties which must be determined by laboratory test, a preliminary sample should be taken from each proposed source of supply at least two weeks before final acceptance. Preliminary samples may be taken from the bank or pit where the material occurs or from the dredging plant if it occurs under water. Additional samples for size or grading determinations should be taken after screening, if screening is required, from bins, cars, scows or storage piles on the job. Frequent samples should be taken and tested on the job by the Inspector (§ 371), particularly in the case of mixed products or when grading is an important factor.

60. Methods of Sampling. (*a*) The precautions to be taken in sampling for either quality, or size or grading, are essentially the same. The greatest care is required to insure obtaining samples which are strictly representative of the material as a whole. Samples of gravel or of material containing gravel should never weigh less than fifty times the weight of the largest fragment present. When the material will all pass a $\frac{1}{4}$-inch screen it is advisable to make the weight of the sample about ten pounds. The minimum weight of sample will of course be governed by the quantity required for the tests to which it will be subjected. Thus, if gravel is to be tested for resistance to abrasion, the sample

should be of sufficient size to produce upon screening at least six pounds each of material passing the 2-inch and retained on the 1-inch screen, and passing the 1-inch and retained on the $\frac{1}{2}$-inch screen. By special direction of the Engineer or the Laboratory samples of gravel and sand may be required of sufficient size to make large concrete specimens for compression tests. This may require as much as two cubic feet of coarse aggregate and one cubic foot of fine aggregate.

(*b*) When sampling from a pit or bank, if the deposit does not appear to be reasonably uniform, individual samples from a number of different points may be necessary to show the possible range in quality or grading. Otherwise a sample should never be taken from a single portion of the deposit, but a composite sample should be prepared by mixing samples taken at different points. Care should be taken to exclude all dirt or extraneous materials which do not form a part of the deposit to be worked. Samples are taken from unopened deposits by digging test holes of such depth as will be represented by the first working face. In a deposit which has been partially excavated samples should be secured from working faces as nearly vertical as possible by scraping the face with a trowel or pick for its entire depth and collecting only that portion so removed.

(*c*) When sampling from bins, cars, barges or storage piles better average samples may be obtained when the material is damp than when perfectly dry because of the greater tendency of perfectly dry particles of the same size to segregate. Composite samples should invariably be prepared by mixing samples taken from various portions of the pile. At each point sampled a hole should be dug and the sample obtained by scraping from the bottom upward on a vertical face. When sampling a number of cars or piles of supposedly the same product, an individual composite sample should be taken from each car or pile which for any reason appears to be different from the others.

CHAPTER IV

HYDRAULIC CEMENT

GENERAL CHARACTERISTICS

61. Classification. There are many classes and subclasses of hydraulic cements, but only a few are of interest in highway work. In fact, it may be said that only one, namely, Portland cement, is extensively used in highway construction. The principal classes, including quicklime, which is closely related but does not possess hydraulic properties, are as follows:

(*a*) Portland cement.
(*b*) Natural cement.
(*c*) Puzzolan cement.
(*d*) Hydraulic lime.
(*e*) Common quicklime.

62. Manufacture. Portland cement is produced by burning to incipient fusion an intimate mixture of finely ground calcareous and argillaceous materials, such as limestone and clay, consisting of approximately three parts of calcium carbonate to one part of silica, alumina and iron oxide, and afterwards finely pulverizing the clinker. Natural cement, called Rosendale cement in certain sections of the country, is made by burning at low heat limestone containing an excess of clay and often considerable magnesia, and afterward finely pulverizing the resulting product. Puzzolan cement consists of an intimate finely pulverized mechanical mixture of slaked lime with blast furnace slag or volcanic scoria of suitable composition, the first mixture often being

called slag cement. Hydraulic lime is produced by burning limestone which contains a small amount of clay and reducing it to powdered form by the addition of just sufficient water to slake the free lime which is present. Common quicklime is produced by burning fine soft limestone to remove carbon dioxide, and is usually obtained in lumps. When just sufficient water is added to slake it to a powder, hydrated lime is produced.

63. Properties. All of the true hydraulic cements possess the property of hardening under water, and when mixed to a paste with water, of setting up to a stone-like mass. When used as a binding medium for other materials such as sand, gravel, and broken stone they, therefore, produce a monolith. When mixed with water certain reactions take place between the calcium, alumina and silica compounds present and new and more stable mineral constituents are formed which interlock and produce an artificial stone. Common quicklime, however, reacts with water to form calcium hydrate, and its hardening is largely due to the later formation of carbonate of lime through absorption of carbon dioxide from the air. Specifications for hydraulic cements may include limitations for a few chemical components which are believed to be deleterious in excessive amount, also strength requirements and certain properties having to do with workability. While exhibiting considerable compressive and tensile strength, hydraulic cements which have set do not exhibit the same degree of hardness and resistance to abrasion possessed by the more resistant types of rock. Their toughness may, however, run fully as high.

SPECIFICATIONS FOR PORTLAND CEMENT

64. Standardization. Among the materials used in highway construction Portland cement is the only one of which it may be said that a single uniform standard specification has been generally adopted. This material is, however,

peculiar in the fact that its quality may be considered irrespective of the class of work in which it is used, the character of other materials which are to be associated with it, variations in the raw materials from which it is made, and the effect of local conditions, such as traffic and climate, upon its usefulness. The present standard, which is briefed in the following paragraphs, has been adopted by the United States Government and the American Society for Testing Materials (Standard C 9–17) and is the result of a joint conference of representatives from both sources, together with representatives of the American Society of Civil Engineers.

65. Definition. "Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum."

66. Chemical Properties. "The following limits shall not be exceeded:

Loss on ignition	4.00 per cent
Insoluble residue	0.85 " "
Sulphuric anhydride (SO_3)	2.00 " "
Magnesia (MgO)	5.00 " " "

67. Physical Properties. (*a*) *Specific Gravity.* "The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland Cement)."

(*b*) *Fineness.* "The residue on a standard 200-mesh sieve shall not exceed 22 per cent by weight."

(*c*) *Soundness.* "A pat of neat cement shall remain firm and hard and show no signs of distortion, cracking, checking or disintegration in the steam test for soundness."

(*d*) *Time of Setting.* "The cement shall not develop initial set in less than 45 minutes when the Vicat needle is

used or 60 minutes when the Gilmore needle is used. Final set shall be attained within 10 hours."

(*e*) *Tensile Strength.* "The average tensile strength in pounds per square inch of not less than three standard mortar briquettes composed of 1 part cement and 3 parts standard sand by weight shall be equal to or higher than the following:

Age at Test	Storage of Briquettes	Tensile Strength
7 days	1 day in moist air, 6 days in water	200
28 days	1 " " " " 27 " " "	300

"The average tensile strength at 28 days shall be higher than that at 7 days."

68. Packages, Marking and Storage. (*a*) "The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net."

(*b*) "The cement shall be stored in such manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness."

69. Inspection. "Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically so ordered."

70. Rejection. "The cement may be rejected if it fails to meet any of the requirements of these specifications. Cement shall not be rejected on account of failure to meet

the fineness requirement if upon retest after drying at 100° C. for one hour it meets the requirement. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample any time within 28 days thereafter. Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment as shown by weighing 50 packages taken at random is less than specified, the entire shipment may be rejected."

SPECIFICATIONS FOR NATURAL CEMENT

71. Standardization. Specifications for natural cement have not received the same amount of attention as for Portland cement. However, the American Society for Testing Materials adopted a standard (C 10–09) in 1909 and its Committee C–1 later recommended that until revision the new methods of tests for Portland cement (C 9–17) be applied to the testing of natural cement. This specification is substantially as follows:

72. Definition. "This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas."

73. Physical Properties. (*a*) *Fineness.* It shall leave by weight a residue of not more than 10 per cent on the 100-, and 30 per cent on the 200-mesh sieve.

(*b*) *Time of Setting.* "It shall not develop initial set in less than 10 minutes" (when the Vicat needle is used) "and shall not develop hard set in less than 30 minutes, or in more than 3 hours."

(*c*) *Tensile Strength.* "The minimum requirements for tensile strength for briquettes 1 square inch in cross section shall be as shown on the table on the following page, and the cement shall show no retrogression in strength within the periods specified."

Age at Test	Storage of Briquettes	Tensile Strength Lbs. per sq. in.	
		Neat Cement	Standard 1:3 Mortar
24 hours	24 hours in moist air	75	...
7 days	1 day in moist air, 6 days in water	150	50
28 days	1 " " " " 27 " " "	250	125

(*d*) *Constancy of Volume.* "Pats of neat cement about 3 inches in diameter, ½ inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours. A pat is then kept in air at normal temperature; another is kept in water maintained as near 70° F. as practicable. These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating."

74. Package, Marking and Storage. These requirements are essentially the same as for Portland cement (§ 68) except that it is specified that a bag of natural cement shall contain 94 pounds and each barrel shall contain 282 pounds.

CEMENT TESTS

75. Chemical Analysis. In the standard specifications for Portland cement the methods of chemical analysis are described in detail, but are of no particular interest to the highway Inspector. For the loss on ignition test a permissible variation of 0.25 is allowed and all results in excess of the specified limit but within the permissible variation are reported as 4 per cent. For the insoluble residue a permissible variation of 0.15 is allowed and all results in excess of the specified limit but within the permissible variation are reported as 0.85 per cent. In like manner a permissible variation of 0.10 for sulphuric anhydride and 0.4 for magnesia are allowed and all results in excess of the specified limits

but within the permissible variations are reported as 2 per cent and 5 per cent respectively.

76. Specific Gravity. The determination of specific gravity is made with a standardized Le Chatelier flask and in brief consists of ascertaining the volume of water-free kerosene displaced by 64 grams of the cement. The weight of cement, divided by the number of cubic centimeters of kerosene displaced, gives the specific gravity of the cement. If a test upon the cement as received falls below 3.10 for Portland cement, a second test is made on a freshly ignited sample.

77. Fineness. The determination for fineness is made by agitating, in a specified manner, 50 grams of the cement upon the proper standard sieve and continuing the agitation until not more than 0.05 gram passes through in one minute. The residue remaining upon the sieve is then weighed and its per cent of the original sample calculated. For Portland cement a permissible variation of 1 is allowed and all results in excess of the specified limit but within the permissible variation are reported as 22 per cent.

78. Normal Consistency. The per cent of water necessary to mix with the cement to produce a paste of so-called normal consistency is ascertained by making trial mixes until a paste is found which upon being tested with the Vicat needle will show a settlement of the needle of 10 millimeters at the end of a ½-minute period. This instrument consists of a movable rod of standard weight and dimensions which is carried in a frame so that when released it will have a downward vertical movement. A removable needle of standard size can be inserted in one end of the rod. The sample of cement paste is held in a standard rubber ring on a glass plate below the needle, which at the beginning of the test is just brought into contact with the upper surface of the paste. The per cent of water necessary to produce a standard 1:3 cement mortar is ascertained from a table of water equivalents for standard mortars compared with

normal cement pastes containing various per cents of water.

79. Soundness. This test is made by first preparing a pat of specified shape and dimensions, from paste of normal consistency (§ 78). The pat is made upon a glass plate and stored in moist air for 24 hours, after which it is placed in an atmosphere of steam just above boiling water for a period of 5 hours. The pat is then examined for distortion, cracking, checking or disintegration.

80. Time of Setting. (*a*) When determining the time of setting of cement a paste of normal consistency (§ 78) is first prepared. The test itself is made either with the Vicat apparatus (§ 78) or Gilmore needle. In both cases the paste is kept in moist air throughout the test.

(*b*) With the first-mentioned instrument the time of initial set is the period elapsing between the time when normal consistency is secured and the time when the needle operating for ½ minute ceases to pass a point 5 millimeters above the glass plate on which the sample rests. The time of final set is the period elapsing between the time when normal consistency is secured and the time when the needle does not sink visibly into the paste.

(*c*) The Gilmore needles are two weighted wire rods. The needle of larger diameter carries a weight of ¼ pound and that of smaller diameter carries a weight of 1 pound. In making a test, one of the needles is held in a vertical position and applied lightly to the surface of the cement paste. Initial set is obtained when the paste will bear the weight of the ¼-pound needle without appreciable indentation. Final set is obtained when in like manner it will bear the weight of the 1-pound needle.

81. Mortar Tensile Strength. A mortar of normal consistency (§ 78) is first prepared from a mixture of water with one part by weight of the cement to three parts by weight of standard quartz sand obtained from Ottawa, Illinois. This sand has been sieved to pass a 20-mesh and be retained on

a 30-mesh standard sieve. The mortar is then molded into standard shape briquettes with a minimum cross section of one square inch and stored for 24 hours in moist air, after which the briquettes are placed under water until ready to be tested. At the end of 6-and 27-day periods of water immersion, at least three briquettes are tested in a tension machine, being subjected to a load applied continuously at the rate of 600 pounds per minute. At each period, the loads required to pull each of the briquettes apart are averaged and reported as tensile strength, in pounds per square inch.

82. Tensile Strength Neat Cement. While this test is not at present specified for Portland cement, it may be required for natural cement. It is made in exactly the same manner as described for mortar (§ 81) except that the briquettes are made from cement paste of normal consistency and one set of briquettes is tested after twenty-four hours' storage in moist air as well as after immersion in water for the additional two periods.

MEASUREMENT

83. Basis of Purchase. Hydraulic cement may be purchased directly on a weight basis, but it is usually purchased by the bag or barrel unit with the weight of the unit specified. Inspection of quantity delivered or used should, therefore, be checked by weight (§ 70) as well as by count of the bags or barrels. Counting empty sacks is not a safe procedure unless checked by counting also the unused material in the shipment of known amount from which the used material has been drawn.

84. Volume and Weight Relations. (*a*) Experiments have shown that freshly sifted Portland cement may weigh as low as 80.3 lb. per cubic foot, while packed cement may weigh as high as 123.2 lb. per cubic foot. As cement is commonly used by volume proportion in construction work, it is, there-

fore, very necessary that specifications state the weight per unit volume which will govern its use in the work specified. For this purpose the two most common assumptions are that one sack of 94 pounds will represent a cubic foot or that one cubic foot will weigh 100 pounds. In the latter case a standard barrel would represent 3.76 cu. ft.

(*b*) The voids in Portland cement are of no practical interest insofar as its use in ordinary mortar or concrete work is concerned. This is because of the fact that when acted upon by water chemical reactions take place which produce entirely different material. Cement is, however, sometimes used as an inert filler in bituminous concrete where no water is employed, in which case its percentage of voids becomes a matter of interest. Upon the assumption that the specific gravity of cement is very close to 3.1 and considering the extremes in weight mentioned in the preceding paragraph, the voids in loose cement may be as high as 58 per cent and in packed cement as low as 36 per cent. Forty per cent of voids may safely be assumed for cement when used as an inert filler. Upon this basis a cubic foot of cement will weigh approximately 116 pounds.

SAMPLING

85. Time and Place of Sampling. Cement should be sampled at least ten days in advance of its acceptance or rejection, when such is decided upon the basis of a 7 day test, but preferably at least 31 days in advance. It may be sampled either at point of manufacture or at its destination. If it is necessary to use it promptly upon arrival at its destination, arrangement should be made for sampling at the factory. Additional samples are advisable if the cement has been stored for long periods since first accepted or if for any reason it is believed to have deteriorated, due to imperfect protection from the weather during shipment or storage.

86. Methods of Sampling. (*a*) Samples taken from the factory may be secured from the conveyor delivering to the bin, from the bins themselves by means of proper sampling tubes, or from the bins at point of discharge. Unless otherwise directed, only composite samples prepared from a number of individual samples should be forwarded to the Laboratory. In no case, however, should a single composite sample represent over 200 barrels or an individual sample over 100 barrels. When sampling from the conveyors or discharges, small samples should be secured at intervals throughout the passage of each 200 barrels and thoroughly mixed to produce the composite samples. When sampling from the bin samples are secured from points well distributed over the face of the bin, and whenever practicable for the entire depth of the material, not to exceed 10 feet. Sampling tubes inserted horizontally may be used where the construction of the bin permits.

(*b*) When sampling from cars or warehouses individual or composite samples are prepared for shipment to the Laboratory as directed. Composite samples should, when possible, be prepared from samples taken from one sack in each 40 sacks, or one barrel in each 10 barrels, in as many different parts of the car or storage space as possible. An individual sample should represent not more than 50 sacks. In no case should a single composite sample represent over 200 barrels, and in lots of less than one car load the sample should represent at least 5 bags. When sampling, each sample from bag or barrel should be taken from surface to center and each sample from bulk shipment should be obtained from top to bottom.

(*c*) Each sample, whether individual or composite, which is forwarded to the Laboratory should weigh between 8 and 10 pounds and be shipped in an air-tight container.

CHAPTER V

BITUMINOUS MATERIALS

GENERAL CHARACTERISTICS

87. Composition. From the standpoint of highway engineering, bituminous materials are materials containing bitumen as an essential constituent. Without confusing himself with the rather involved technical definition, the Inspector may consider bitumen as being the hydrocarbon compounds constituting the whole or the greater part of petroleum, asphalt and tar products, which will dissolve in carbon disulphide. Bitumen, as used in highway work, may exist in liquid, semisolid, or solid form, but if semisolid or solid it may be rendered liquid by the application of heat.

88. Classification. Two main groups of bituminous materials exist: (1) those consisting of or containing petroleum or asphalt products, and (2) those consisting of or containing tar products. Both of these groups may be classified according to their principal uses as follows:

Surface Treatment of Highways:
- Dust Preventives
- Carpeting Mediums
- Seal Coating Materials

Incorporation in the Highway Structure:
- Bituminous Cements
- Bituminous Fillers
- Bituminous Aggregates.

In addition, certain tar products are used as impregnating materials for wood block. In both groups the consistency

of the bitumen may run from very fluid to almost solid for the various purposes listed.

89. Manufacture. (*a*) The desired consistency of bituminous materials is usually obtained by one or more manufacturing processes, such as distillation, oxidation or blowing, fluxing, and emulsification. In distillation, two classes of products are formed, distillates and residues. The former are almost always relatively thin liquids possessing no binding qualities. Residues, on the other hand, run from liquids to solids, according to the extent of distillation or amount of distillate removed. Water and the more volatile constituents of crude petroleum are sometimes removed by distillation and sometimes by heating the material in a coil of pipe so that pressure is developed. The hot oil is then allowed to expand suddenly and the water existing as steam leaves without producing foaming. This process is called topping.

(*b*) By blowing air through certain fluid residues at a proper temperature they may be converted by chemical action and without material distillation into semisolid or solid products. Such products are known as blown asphalts. By mixing a semisolid or solid with a liquid bituminous material the former is softened. This process, known as fluxing, is frequently conducted at the paving plant and is subject to inspection. Most fluxes are fluid residues, but in some cases distillates are employed, and the resulting product is called a cut-back. Emulsified or emulsifiable bituminous materials are those to which a saponifying agent or soap has been added so that they may be mixed with water to any desired extent and thus be rendered more fluid.

90. Temperature Control. In order to be properly applied or used in highway work many bituminous materials must be made temporarily more fluid by the application of heat. The heating process may be conducted in open kettles, tank cars, or tank wagons, and when fluxing is required,

prolonged agitation of the heated material is necessary as well. In some cases the temperature to which the material must be raised may cause loss through volatilization of some of its lighter constituents, particularly if agitation is required, with the result that if cooled the material will become harder or more solid than it was at first. Furthermore, if the temperature is raised too high, chemical reactions may take place which will injure or ruin the product for highway purposes. At very high temperature, the product may even catch fire and burn. Proper control of temperature during use is, therefore, a vital matter which should be closely observed by the Inspector. Specifications usually place a maximum temperature limit at which the material may be heated and sometimes state that all material heated above such temperature shall be rejected. In addition to the bituminous material proper, it may also be necessary to heat broken stone, gravel or sand with which it is to be mixed. In such cases, just as much necessity exists for proper temperature control of the mineral matter as for the bituminous material. When mixed with a mineral aggregate, the bituminous material exists in relatively thin films surrounding each particle, and overheating of the aggregate will injure the bituminous material more rapidly than overheating to the same extent in a kettle.

91. Effect of Water. It is very doubtful if the presence of water in most bituminous materials before use results in any injury to the material itself. With few exceptions, however, bituminous road materials are free from water as manufactured, and specifications often require this. The presence of even a very small amount of water in bituminous materials which have to be heated may seriously interfere with their proper use or application. Thus, a few tenths of 1 per cent of water may cause the product to foam almost completely out of a kettle when heated rapidly above the boiling point of water, and considerable time may be consumed in driving off the water in order to heat the

material to the desired temperature without foaming. Suitable precautions should, therefore, be taken to prevent water from becoming mixed with a bituminous material or finding its way into the heating tank or kettle. In some cases, such as shipment of material in a tank car fitted with leaky steam coils for heating purposes, it may be necessary to reject bituminous material containing water owing to the impossibility of heating it to the temperature desired for use. Water which has accumulated on the surface of hard bituminous materials, as in the heads of barrels stored in the open, may often be removed with a large sponge before the material is introduced into the kettle.

92. Transportation and Storage. Large quantities of fluid bituminous materials are ordinarily shipped to the consumer in tank cars of from 4000 to 12,000 gallons capacity. These tank cars are, as a rule, equipped with steam coils which may be connected from the outside with the boiler of a road roller or tractor, in case it is necessary or desirable to heat the material before unloading. Semisolid materials are also sometimes shipped in tank cars, in which case it is very important that the coils be so designed and placed as to insure efficient heating of the entire contents. A very large proportion of the semisolid and solid materials is, however, shipped in barrels or drums. For the harder grades which require fluxing, open-head slack barrels are often used. These barrels are clayed on the inside so that, after cutting the hoops, the staves may be stripped from the material with little or no waste. Slack barrels hold from 300 to 400 pounds of material, depending largely upon its specific gravity. In some cases, slack barrels may be double-headed, but in any event they should be stored on end or otherwise they are apt to cave in, due to unequalized strains produced by the slow flow or deformation of the bituminous material within. Double-head tight barrels of approximately 50 gallons' capacity, but sometimes varying from 40 to 60 gallons' capacity, are largely used for semi-

solid and viscous bituminous materials. They are much stouter than the slack barrel, but when stored for long periods should be placed on end. Thin sheet metal drums are also used to a considerable extent in place of barrels for the transportation of semisolid bituminous materials. These drums are made with both single and double heads. They are of light weight and hold from 375 to 525 pounds of material. They are readily dented and sometimes punctured during loading or unloading and require careful handling, as punctures are practically impossible to repair and may result in the loss of considerable material during storage. They cannot be stacked without slowly pressing out of shape and bursting.

PETROLEUM AND ASPHALT PRODUCTS

93. Types of Petroleum. There are two distinct types of crude petroleum: the paraffin with a greasy base; and the asphaltic with a sticky or adhesive base. From a chemical standpoint, there is also an intermediate type known as semiasphaltic. Paraffin petroleums are of interest from the standpoint of highway engineering only as dust preventives or for the manufacture, by distillation, of residual fluxes which are used to soften asphalts to any desired consistency. Crude asphaltic petroleums are sometimes used directly in the surface treatment of roads, but are more frequently distilled to proper consistency for one of the uses listed (§ 88). The oxidation process known as blowing is frequently employed in connection with distillation to produce road and paving materials from semiasphaltic petroleums. Blowing is also used to some extent in refining asphaltic petroleums when it is desired to produce residues the consistency of which is affected comparatively little by temperature changes and where high ductility is not considered an important characteristic.

The following table shows the source of the more common

petroleums used in the United States, and their residual products which are of interest in highway work:

PETROLEUM PRODUCTS

Crude Material	Refining Process	Refined Product	Use
Paraffin Petroleum Pennsylvania Ohio, Ind. or Lima	Distillation	Residual oil	Flux
Semiasphaltic Petroleum Mid-Continent Texas Southern Illinois	1. Distillation 2. Distillation & Blowing	Residual oil Blown oil	Dust preventive Carpeting medium Flux Seal coat material Asphalt cement Joint filler
Asphaltic Petroleum California Mexican Trinidad	1. Topping 2. Distillation 3. Distillation & Blowing	Topped oil Residual oil Asphalt Blown asphalt	Carpeting medium Carpeting medium Flux Seal coat material Asphalt cement Seal coat material Asphalt cement Joint filler

94. Petroleum Distillates. Petroleum distillates are relatively thin fluids running from almost colorless to opaque reddish brown. The more volatile distillates which contain an appreciable quantity of gasoline or naphtha are sometimes used as fluxes for asphalts in the manufacture of cutback products. The heavier, more viscous and nonvolatile distillates resemble inferior lubricating oil and are useful only as dust layers, for which purpose they may be applied cold. They seldom, if ever, exceed 0.920 specific gravity or 12.0 specific viscosity (§ 123) at 25° C. (77° F.).

95. Liquid Petroleum Residues. (*a*) Liquid petroleum residues are dark brown to black products varying in consistency from thin fluid to almost semisolid, according to the character of the original oil and the extent to which it has been distilled. Those produced from paraffin petroleums are greasy and are of value only as fluxes for asphalts. The thin fluid semiasphaltic residues are sometimes used as dust

preventives, while the more viscous and less volatile are used as fluxes and to some extent as carpeting mediums, although they are frequently deficient in cementing qualities. The asphaltic residues produced by topping or distillation are usually quite viscous and possess or develop considerable binding value. They are used as carpeting mediums and, if free from volatile constituents, as fluxes for the hard asphalts.

(*b*) Residual carpeting mediums for cold application are seldom less than 0.93 or more than 0.97 specific gravity. They usually show a specific viscosity (§ 123) of from 80 to 120 at 25° C. (77° F.). The better grades for hot application have a specific gravity of over 0.98. They show a float test of over 60 seconds at 32° C. (90° F.), but a specific viscosity at 100° C. (212° F.) of less than 60.

(*c*) Residual fluxes vary in specific gravity usually between the limits of 0.92 for paraffin residues and 1.02 for asphaltic. Their consistency varies greatly but, in general, increases with their specific gravity. They should possess an open flash point higher than the temperature to be used in fluxing and should lose little or no volatile material at that temperature.

96. Asphalts and Asphalt Cements. (*a*) Asphalts and asphalt cements are solid and semisolid products produced from petroleum by processes of distillation or blowing, or similar products existing as such in natural deposits. Those properly produced from petroleum are practically pure bitumen, while the native asphalts sometimes carry a high percentage of mineral and organic impurities. Petroleum asphalts, often called oil asphalts, are usually manufactured so as to be of suitable consistency for use. When this is so, they are called asphalt cement or A. C. If too hard for use, they are called refined asphalt or R. A. Native asphalts are usually too hard for direct use in highway work and, after refining to produce an R. A., must be combined in suitable proportions with a flux to produce an A. C. of proper con-

sistency for use. The bitumen of a fluxed native asphalt may be very similar if not identical to that of an asphalt cement of the same consistency produced by the distillation of an asphaltic petroleum. Blown asphalts, however, are considerably different in their physical properties, the most marked difference being a much higher melting point for a given penetration and a much lower ductility and lower specific gravity. Asphalts and asphalt cements range in penetration (§ 125) at normal temperature, usually between the limits of 0 and 200. If an asphalt shows a lower penetration than 40 it almost invariably has to be fluxed before use.

(*b*) Petroleum asphalts and asphalt cements most commonly used in the United States and which are manufactured by distillation without blowing are produced from California and Mexican petroleums and sometimes from mixtures of one of these oils with a semiasphaltic oil. To produce asphalt from the semiasphaltic petroleums such as the Texas, Mid-continent and Southern Illinois oils, usually necessitates blowing as well as distillation, although subjecting the oil to a special preliminary cracking process may make blowing unnecessary. In certain instances, asphalts are manufactured from the sludge obtained by treating petroleum distillates with sulphuric acid, in which case they are known as sludge asphalts.

(*c*) The most common native asphalts used in this country are obtained from the Island of Trinidad and from Bermudez, both in Venezuela. Solid brittle bitumens, known as Gilsonite and Grahamite, which occur in different parts of the United States, are also used to some extent, particularly in combination with oils or asphalts which have been blown. The native asphalts, Trinidad and Bermudez, have to be refined before they are fluxed to produce asphalt cements. The refining process consists in heating them so as to remove water, gas and some of the coarse organic and mineral impurities. In both asphalts, an appreciable

amount of non-bituminous material remains after refining, but the refined product as marketed is of quite uniform composition. Refined Bermudez asphalt contains approximately 94 per cent bitumen and refined Trinidad asphalt 56 per cent bitumen. It is evident that asphalt cements produced by fluxing these refined products will vary in their bitumen content according to the amount of flux, consisting of practically pure bitumen, which is used.

97. Asphalt Fillers. There are two types of asphalt fillers used for filling joints in pavements, the poured joint filler, and the prepared or premolded joint filler. The former is really an asphalt cement, usually produced by the blowing process. It may be a straight petroleum product or one containing Gilsonite or Grahamite. The premolded fillers, sometimes called expansion joints, are bituminous strips of suitable width and thickness. They may be of the same composition as the poured joint filler or a mixture of asphalt cement with such substances as limestone dust, silica, or shoddy dust. Sometimes they are reinforced with fabric and sometimes they consist of one or more layers of fabric or felt saturated with asphalt. Prepared expansion joints reinforced or armored with metal are also manufactured.

98. Cut-back Asphalts. Cut-back asphalts or asphalt cements are those which have been fluxed with a distillate, usually of a volatile nature. The purpose of the distillate is to temporarily soften the asphalt cement which has the ultimate desired consistency but which cannot be readily used in its original state in the type of treatment or construction specified. Such products should, after use, rapidly lose the distillate flux by volatilization and return to approximately the same consistency as the original asphalt cement. Thus, if it is desired to apply, without heating, an asphalt cement to a road surface, the asphalt cement may be fluxed with a volatile distillate until sufficiently fluid to apply cold.

99. Emulsions and Emulsifying Oils. Petroleum or asphalt products are ordinarily insoluble in water. They may,

however, be made miscible with water by first mixing them with soap or soap-forming constituents. Such products can then be brought to any desired degree of fluidity by the addition of water. The emulsifying agents commonly employed are oleic acid or cotton seed oil, together with caustic soda, potash, or ammonia. In addition, carbolic acid, pine oil, and various other materials are sometimes used. The manufacture of an emulsifiable asphalt is often a difficult matter, resulting in a product of rather unstable equilibrium. If this equilibrium is once destroyed, the product is rendered unemulsifiable without the application of heat. This equilibrium is usually destroyed when the material is forced into intimate contact with stone, sand, gravel, etc. After application to a road, therefore, the material is not susceptible to removal by the action of water.

100. Rock Asphalt. (*a*) Rock asphalt is limestone or sandstone naturally impregnated with asphalt. It is mined or quarried from natural deposits by methods similar to those employed in rock quarrying. It is then usually crushed in roll or hammer crushers, after which further treatment may be required to make it suitable for highway purposes, where it is used directly as a paving material. Thus, in order to secure the proper amount of asphalt or bitumen it may be necessary to mix two or more grades of rock asphalt containing different percentages of bitumen. It may even be necessary to add more asphalt or to soften that already present by the addition of a suitable amount of flux.

(*b*) Bituminous limestone may be of a semi-crystalline, conglomerate, or chalky nature. The purer carbonate rocks crush down to a fine powder, each particle of which appears to be impregnated with bitumen. Under compression, especially at an elevated temperature, the better grades congeal to form a dense tough mastic. They occur in various parts of the world, but the domestic deposits only are of particular interest as paving materials in this country. The

best known of these occurs in Uvalde County, Texas, as a shell limestone or conglomerate impregnated with hard asphalt.

(*c*) In bituminous sandstones, while the bitumen permeates the natural rock, it appears to coat the mineral particles rather than to impregnate them. In their preparation for use the sand grains are not necessarily crushed to produce a mastic with the bitumen, but may be merely broken down or partly separated. A prepared bituminous sandstone may, therefore, have the general appearance of a sheet asphalt paving mixture, although the mineral particles are seldom as well graded. A deposit occurring in Kentucky and known as Kentucky rock asphalt has probably been most widely used in this country, although bituminous sandstones are found in various other portions of the United States, and certain deposits occurring in California have also been used in paving work.

TAR PRODUCTS

101. Types of Tar. (*a*) There are two principal types of tar of interest in highway engineering, — coal tars and water gas tars. The former, as their name implies, are derived from coal. They are incidentally produced as distillates in the manufacture of gas or coke by the destructive distillation of bituminous coal. According to the main object of the process which involves different types of plant apparatus and largely influences the character of the tar, coal tars may be subdivided into two groups, gas-house coal tars and coke-oven tars. Water gas tars are derived from petroleum products by a process of destructive distillation in the manufacture of carburetted water gas. While their origin is entirely different, they closely resemble coal tars, particularly when refined for use in highway work. Crude tars are sometimes used directly in the surface treatment of roads, but are usually distilled to suitable consistency. All

yield semisolid or solid pitches if distilled to a sufficient extent and, therefore, any desired consistency of the sticky tar residuum or refined tar may be obtained by distillation only. The blowing process is also sometimes employed, particularly in the manufacture of fillers.

(*b*) Both physically and chemically, tar products are quite different from petroleum and asphalt products of the same consistency. They are much more susceptible to temperature changes than the latter and tend to harden more rapidly when exposed to atmospheric conditions. These relative properties offer certain advantages and disadvantages which are of considerable interest in highway engineering. Tar products are used as dust preventives, carpeting mediums, seal-coating materials, bituminous cements, fillers, and also as impregnating materials for wood block. Owing to their very pronounced susceptibility to temperature changes, tar cements are not well adapted for and are seldom used in the construction of fine aggregate bituminous concrete highways.

(*c*) Tars contain a widely varying percentage of free carbon which may be considered as an inert impurity existing in the form of finely divided soot. This material is suspended quite uniformly throughout the tar and is insoluble in carbon disulphide (§ 133). In water-gas tars it is present to a very limited extent, sometimes amounting to but a few tenths of 1 per cent, while in gas-house coal tars it may amount to 30 per cent or more. Coke-oven tars usually carry a smaller amount, but seldom less than 3 per cent. As free carbon is nonvolatile, it always remains in the residue of a tar subjected to distillation and its percentage of such residue, therefore, becomes higher as the percentage of distillate removed increases during distillation. The amount of free carbon in a refined tar is often controlled by blending two or more crude tars, which contain different percentages of free carbon, before the process of distillation is commenced.

102. Liquid Refined Tars. Liquid refined tars are either tar residues or mixtures of such residues with a smaller amount of crude tar or tar distillates. They are black in color and usually have a strong odor of tar oils and naphthalene. They vary in consistency from those which are sufficiently fluid to apply cold to those which require heating before application. They are used to some extent as dust layers but more frequently as carpeting mediums. Those which are viscous possess considerable binding power and even the thin fluids rapidly develop binding qualities after application. Those which are to be applied cold often contain a small amount of water which materially reduces their viscosity. A high percentage of free carbon is considered undesirable, as this material tends to interfere with absorption of the tar proper by the road surface. The specific gravity of liquid refined tars varies greatly, depending upon their consistency and the amount of free carbon present. It is, however, almost invariably greater than 1.100. This fact alone may serve to differentiate liquid refined tars from liquid petroleum residues, although their characteristic odor is usually sufficient for this purpose.

103. Semisolid Refined Tars. (*a*) The semisolid refined tars are usually very viscous tar residues intended primarily to serve as bituminous cements in the road structure or as seal-coating materials. Because of their tendency to harden with age as well as their susceptibility to temperature changes or tendency to become brittle in cold weather, they are ordinarily much softer than asphalt cements manufactured for the same purpose. In fact, they are so soft that their consistency is seldom determined by the penetration test (§ 125), the float test (§ 124) being used for this purpose. They have a much higher specific gravity than the asphalts, unless the latter contain a considerable amount of mineral matter, as in the case of Trinidad asphalt. Their specific gravity, depending largely upon their free carbon content, is seldom less than 1.15 or greater than

1.30. When used in bituminous concrete, the free carbon present should be calculated as filler rather than as bitumen.

(*b*) Sometimes the heavy tar residues are cut back with a volatile distillate to produce a material for maintenance by cold patching. Such products are commonly known as cold patch tars.

104. Pitch Fillers. Poured joint fillers are manufactured from tars by distilling and blowing the residue to the desired melting point. They are often quite hard and brittle, contain a high percentage of free carbon, show a high specific gravity and a melting point of 45° C. (113° F.) or higher. They are much more susceptible to temperature changes than are the blown petroleum or asphalt products prepared for the same purpose. The prepared tar expansion joints consist of one or more layers of fabric, felt or porous paper saturated with refined tar.

105. Creosoting Oils. Creosoting oils originally included only certain distillates of coal tar rich in oxygenated hydrocarbons known as cresols. The term is now commonly applied not only to the creosote distillates of coal tars but also to other tar products which are used to impregnate wood. Creosoting oils may be divided into two general classes, heavy distillates of coal tars and water gas tars, and residual tars or oils containing tar residues. The latter class may be very fluid refined water-gas or coke-oven tars or mixtures of refined tars with tar distillates. Petroleum products are seldom used as wood preservatives.

MEASUREMENT

106. Weight Basis (*a*) The harder asphalt cements, refined asphalts and tar pitches are commonly purchased and, therefore, measured by weight, and all materials used in bituminous mixtures are commonly measured on a weight basis. Because of considerable difference in specific gravity

as well as the presence of impurities the weight of a bituminous material does not represent a constant which can necessarily be taken by the Inspector without qualification. When purchase is made by weight in tank car lots, freight weights are usually accepted as a basis for payment. If, however, shipment is made in barrels or drums, the weight of such containers should be ascertained and deducted from the gross weight unless purchase is made and clearly understood to be upon a gross weight basis.

(*b*) The aggregate weight of containers often represents an appreciable percentage of the gross weight of bituminous materials. Thus slack barrels weighing 20 pounds and each holding 300 pounds of bituminous materials will constitute over 6 per cent of the gross weight and amount to 125 pounds per gross ton. Double-head tight barrels may weigh from 60 to 70 pounds each and frequently approximate 15 per cent of the gross weight of a shipment. Thin sheet metal drums are lighter but will affect the net weight to some extent.

(*c*) Sometimes purchase is made upon the basis of actual weight of bitumen delivered and when bituminous materials, containing an appreciable amount of impurities, are involved, recourse must be had to laboratory test reports in estimating the actual weight of bitumen represented. This is a very necessary basis for estimating the percentage of bituminous material to be used in bituminous mixtures, for it is evident that the serviceability of such mixtures will largely depend upon the presence of the proper amount of bitumen, which is the active binding material. It is also a very reasonable basis of purchase, as it is evident that a ton of asphalt containing 100 per cent bitumen will be the approximate equivalent of 1.5 tons of asphalt containing 35 per cent of mineral matter or other impurities. The specific gravity of a bituminous material may also play an important part in the estimate of quantities, but this can best be considered under the volume basis of measurement.

107. Volume Basis. Fluid bituminous materials and sometimes the semisolids and solids as well are purchased upon a volume basis or by the gallon. In the last analysis the volume of bitumen purchased and used is of more technical importance to the Engineer than is its weight. The volume basis, however, has its disadvantages, and the actual

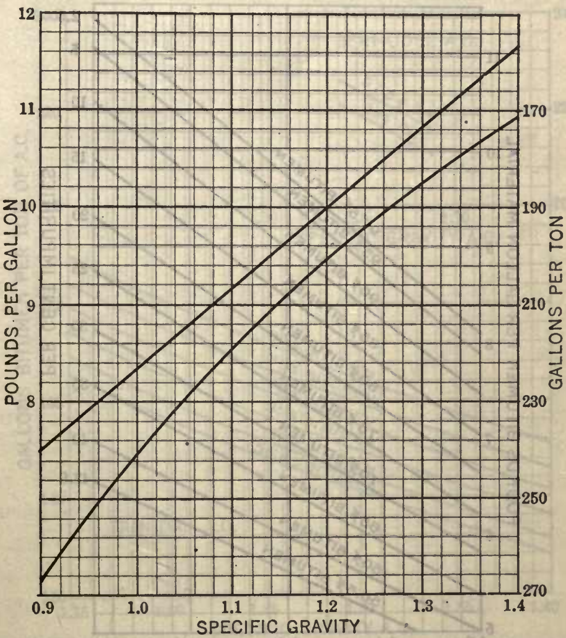

Fig. 7 Weight and Volume Relations for Bituminous Materials

determination of volume may in some cases necessitate the use of weights. When this is done the specific gravity of the material must of course be taken into account. The volume content of certain containers, such as cylindrical tanks, is not difficult to determine, but when shipment is made in small containers such as barrels, frequently of different dimensions and filled to different levels, the matter of volume measurement in bulk becomes so difficult as to

be impracticable. Moreover, in measuring the relatively small quantities used in mixing batches of bituminous aggregate, adhesion of the material to the inside surface of the container is such a variable as to make volume measurement extremely inaccurate. In addition, before measurement it is frequently necessary to heat the material to a

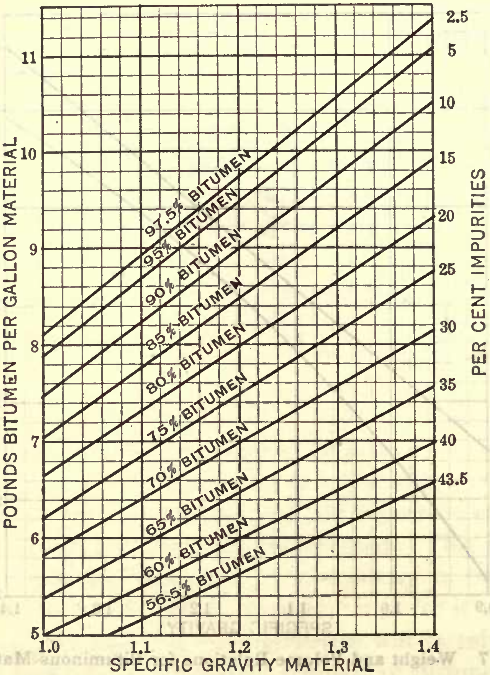

Fig. 8 Weight of Bitumen per Gallon of Bituminous Material

relatively high temperature to render it sufficiently fluid for use. Volume changes then occur which depend not only upon the exact increase in temperature, but upon the response to such increase made by the particular material under consideration. This change in volume with change in temperature is a function of the coefficient of expansion which varies for different types and grades of bituminous

materials (§ 108). Moreover, if purchase is made upon the basis of actual bitumen delivered or used, the volume method of measurement becomes involved and confusing.

(b) In translating weight units to volume units and vice versa, the specific gravity of the material should be taken into account. These relations are shown in Fig. 7.

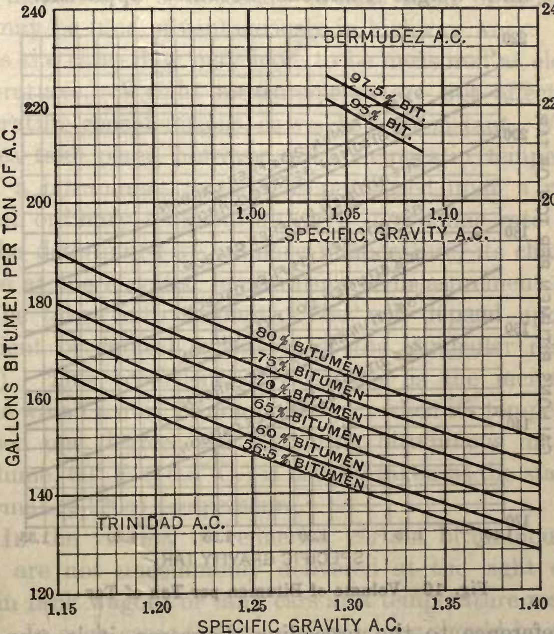

Fig. 9 Volume of Bitumen per Ton of Asphalt

If impurities are present to a known extent and it is desired to ascertain the weight of bitumen per gallon of material or the number of gallons of bitumen per ton of material, Figs. 8 to 10 will be found useful. The diagrams in these figures have been prepared from the most reliable data obtainable relative to the specific gravity of the usual impurities present in the types of materials illustrated. For all practical purposes, petroleum products may be con-

sidered as 100 per cent bitumen and are, therefore, not shown in Figs. 8 to 10, as the curves would be identical with Fig. 7.

When it is realized that the actual volume of bitumen present in a road surface is the vital consideration so far as quantity is concerned, the importance of appreciating volume and weight relations becomes apparent. Thus,

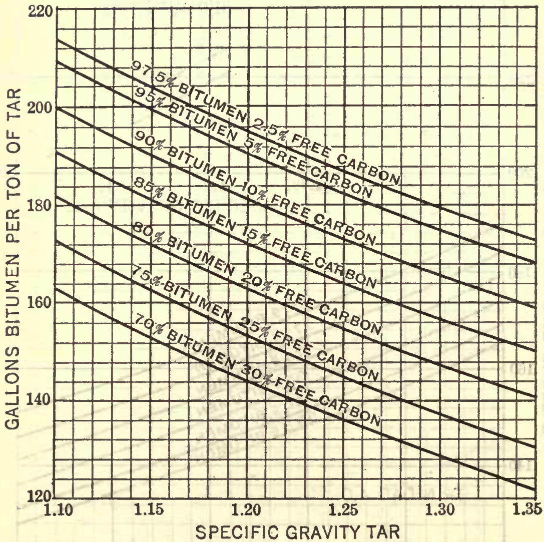

Fig. 10 Volume of Bitumen per Ton of Tar

upon reference to the preceding diagrams, it is seen that 2000 pounds of an oil asphalt of 1.03 specific gravity equaling 234 gallons (Fig. 7) is the equivalent in volume of bitumen to 3020 pounds of Trinidad asphalt cement of 1.3 specific gravity and 70 per cent of bitumen, which contains 155 gallons of bitumen per ton (Fig. 9). This means that if a given number of gallons of bitumen per square yard is required to construct a certain type of pavement, each ton of the oil asphalt will construct 1.5 more yardage than a ton of the Trinidad product or, in other words, for each

mile of a given pavement constructed with the latter, 1.5 miles can be constructed with the same tonnage of the former.

108. Temperature Corrections of Volume. (*a*) Whether liquid or not at ordinary temperature, all bituminous materials containing 50 per cent or more of bitumen become fluid upon heating to a sufficiently high temperature. In many instances it is necessary to heat them in order that they may be used advantageously in highway work. When such is the case, they may have to be measured at elevated temperatures. Weight measurements are not affected by temperature considerations, as weight is a constant. Volume changes take place, however, with changes in temperature and if a bituminous material is purchased upon a volume basis at ordinary temperature, or if its volume rate of use is to be determined at ordinary temperature, its change in volume at the elevated temperature of measurement or use must be taken into account. This will depend upon the coefficient of cubical expansion of the particular material (§ 122). This coefficient of expansion is the increase in volume which a unit volume undergoes when its temperature is raised one degree. In measuring bituminous materials by volume, 60° F. (15.5° C.) is usually taken as the standard or normal (§ 120*a*) temperature.

(*b*) In the vicinity of refineries, certain bituminous materials are not uncommonly delivered at the sight of the work in tank wagons or tank cars at a temperature ready to apply. In such cases the basis of purchase should be clearly set forth in the specifications and, if by volume, a coefficient of expansion or rate of increase in volume with temperature should also be given. In most cases an arbitrary figure is previously agreed upon. Thus, for residual petroleums the coefficient of expansion is often assumed as 0.0004 per degree F. This means that a gallon of oil at 60° F. will expand to 1.0004 gallons at 61° F., 1.0008 gallons at 62° F., etc. A deduction of 0.4 per cent is, therefore, made for every increase of 10 degrees over 60° F. in ascertaining the volume

at normal temperature. As an example, if a tank wagon having a capacity of six hundred gallons is filled with the oil at a temperature of 260° F. the volume of oil at 60° F. would be 555.5 gallons. For such determinations use may

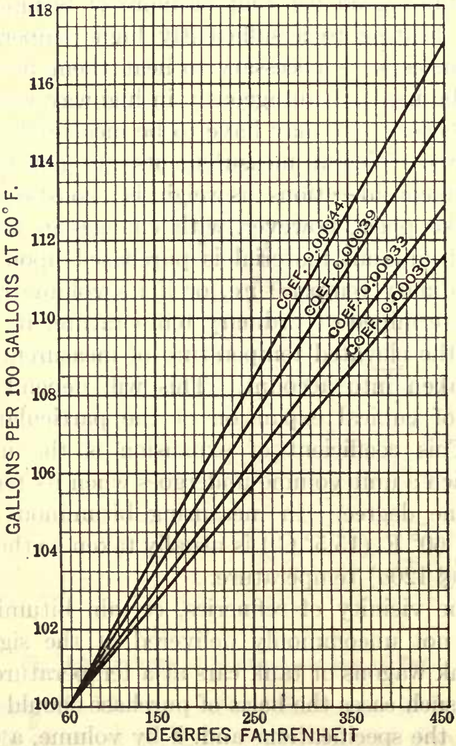

Fig. 11 Volumes at Elevated Temperatures Equivalent to 100 Gallons at Normal Temperature

be made of the following formula in which V is the volume at normal temperature, V', the observed volume at an elevated temperature and T is the observed temperature in degrees Fahrenheit.

$$V = \frac{V'}{.0004(T - 60) + 1.}$$

(c) The coefficients of expansion of materials of the same type and grade vary somewhat, but in practical work an average coefficient may be assumed for certain classes which is sufficiently close for ordinary use. Such approximate coefficients are shown in the Table on the following page.

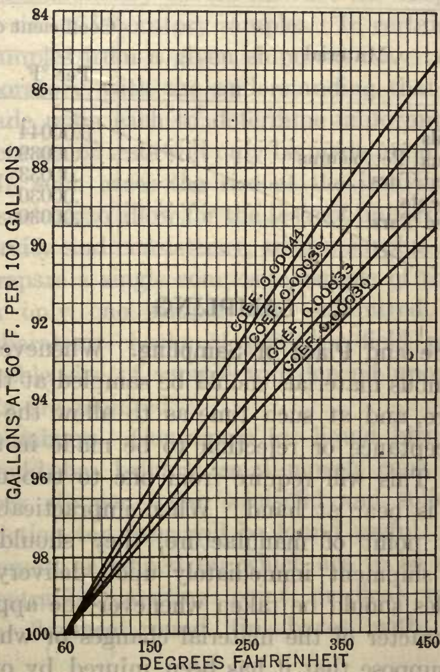

Fig. 12 Volumes at Normal Temperatures Equivalent to 100 Gallons at Elevated Temperatures

Figures 11 and 12 illustrate volume and temperature relations as affected by the various coefficients of expansion given in the Table. The first shows for various Fahrenheit temperatures the number of gallons equal to 100 gallons at 60° F. The second shows the number of gallons at 60° F. represented by each 100 gallons at increased temperatures. When temperatures are taken by Centigrade thermometers,

the equivalent of the Fahrenheit scale (§ 120*b*) should be ascertained before using these diagrams in making volume corrections.

Approximate Coefficients of Expansion of Bituminous Materials

Material	Coefficient of Expansion	
	Per °F.	Per °C.
Creosoting Oils	0.00044	0.00080
Liquid Residual Petroleums	.00039	.00070
Liquid Refined Tars	.00033	.00060
Asphalt Cements	.00030	.00055
Heavy Refined Tars	.00030	.00055

SAMPLING

109. Time and Place of Sampling. Whenever practicable, bituminous materials should be sampled at the point of manufacture, and at such time as to allow the tests controlling acceptance or rejection to be made in advance of shipment. This will require from one to two days if the laboratory is near at hand. When impracticable to take samples at point of manufacture, they should be taken from each shipment immediately upon delivery. In addition, samples should be taken whenever the appearance or general character of the material changes or when there is reason to suppose that it has been injured by overheating. Frequent sampling during use is often necessary when the Inspector is required to make paving plant tests having to do with control of consistency. Thus, when the material is fluxed or maintained in heating kettles at an elevated temperature for periods of twelve hours or more, at least one sample should be taken and tested for consistency each day during its use.

110. Size of Samples. Samples of approximately one quart or two pounds in weight should be submitted to the

Laboratory except when only a check test of consistency is to be made of asphalt cement or heavy refined tar. In such cases, where the penetration, melting point, or float test is to be made, three-ounce samples will be sufficient.

Where practice other than the above is to be followed the Engineer or Laboratory should instruct the Inspector as to the proper size of laboratory samples. In certain cases, two or more samples from a given shipment may be submitted to the laboratory, with the understanding that a few tests will be made upon each to determine uniformity, and that the complete set of tests will only be made upon a composite sample. In such cases the size of the individual samples should be such as to allow for the tests of uniformity, usually specific gravity and consistency, with a surplus amply sufficient to prepare a single composite sample of the same size as though only one sample were submitted. For daily routine laboratory checks of plant or field practice, the most desirable size of sample will depend upon just what check tests are required.

111. Containers. Containers for liquid bituminous materials should be 1-quart, small-mouth cans with screw cap or cork stopper. For semisolid and solid materials, 1-quart friction top cans will be found useful. Samples of asphalt cement or refined tar which are to be subjected to check penetration, melting point, or float test may be placed in 3-ounce round tin boxes with tight-fitting cover.

112. General Precautions. In general samples should be taken so as to represent as nearly as possible an average of the bulk of material sampled and, in most cases, should also be selected with a view to ascertaining the maximum variation in characteristics which the material may possess. Great care should be taken that the samples are not contaminated with dirt or any other extraneous matter and that the sample containers are perfectly clean and dry before filling. When kerosene is used for cleaning sampling

tools, it should be completely removed by wiping before the tools are again used for sampling. When in the open, materials should be sampled preferably during dry weather, but if taken in rainy weather care should be exercised to prevent water from being introduced into the sample can. Sampling bituminous materials is, at best, dirty work and extreme care should be taken by the Inspector that his samples do not become contaminated with water, dirt, chips of wood, paper, or other extraneous material which would tend to vitiate test results. Immediately after filling, the sample containers should be tightly closed and properly marked for identification. They should be packed for shipment in such manner that leakage of contents or contamination by excelsior, paper or other packing material during transit is entirely prevented, as well as obliteration or removal of the identification marks.

113. Sampling from Pipe Lines. When loading tank cars, barrels, or drums from a storage tank, cooler, or still, or when unloading tank cars, drip samples may be taken from the discharge pipe. The material should be allowed to flow for a short time before the first sample is taken in order to free it from material remaining after its last use. The drip valve inserted in the line should be so regulated that the operation of collecting continues through the entire period of discharge. Unless the contents of a tank, cooler, or still are thoroughly agitated during the period of discharge, at least three drip samples should be taken, each representing approximately one third of the amount discharged. It is, however, advisable that no single sample should represent more than one tank car if the loading of tank cars is being inspected.

114. Sampling Directly from Tanks. (*a*) When for any reason it is not advisable to take drip samples from storage tanks or tank cars, samples may be taken directly from the tanks. Unless the material is quite liquid and being thoroughly agitated during sampling, three samples should be

taken, one from the top, one from the bottom, and one from the center of the tank. For materials which are fluid, the bottom sample may be taken from the discharge pipe, through which a sufficient amount of material is first allowed to flow so as to clean it properly. Such material should be discarded or returned to the top of the tank. If there is no outlet at the middle of the tank, a thief sample may be taken by lowering a properly weighted closed bottle or can to the center of the tank and then removing the stopper or cover by means of a stout cord or wire to which it is attached. The necessity of sampling from different levels is apparent when it is considered that a storage tank may contain the product of a number of stills and even a tank car may be partially filled from the last portion of one still and the difference made up from the contents of another still. Moreover, incomplete fluxing may have been conducted in the tank.

(*b*) If samples are taken from tank cars or distributors just before or during use of their contents, three samples may be taken from the discharge, one shortly after the material begins to flow from the discharge, one when the contents of the tank are about half removed, and one when the tank is nearly empty. In the case of distributors of 1000 gallon capacity or less the three samples may be combined to produce a single composite sample.

(*c*) Tanks or tank cars containing cold semisolid or solid bituminous materials should be heated so as to render their contents fluid before samples are taken. If, however, for any reason it is desired to obtain a preliminary sample the material may be sampled through the dome or top manhole by the use of a perfectly clean hot shovel.

115. Sampling from Barrels and Drums. (*a*) Separate samples should be taken from not less than 3 per cent of the containers and, when sampling from car loads, one sample should be taken from each 20 packages and fraction of 20 over 10 and identified with the car number. As it is quite

possible that various lots of different grades of material may have become inadvertently mixed, the packages to be sampled should be carefully selected with reference to their position in the shipment and the manufacturer's markings which they may carry. Such markings should be recorded for every container sampled, and used as a means of identification. In no case should two adjacent containers be sampled unless they bear different markings, or appear to contain different material.

(*b*) When the material is semisolid or solid, samples should be taken at least three inches below the surface. This is advisable not only because the surface may be contaminated with dirt, but because when a container is first filled with hot material considerable contraction takes place upon cooling and the container may afterwards be topped by running in additional material. It is quite possible that through mistake the material used for topping may be of a different grade, and samples taken from the top will not, therefore, represent the consignment. For this reason, when shipment is made in double-head barrels, it is good practice to occasionally up-end a barrel selected for sampling, and sample from what was the bottom.

(*c*) Samples of solid products may be chipped out with a hatchet. If the material is too soft to be chipped out a central portion of the top surface from 5 to 10 inches long and 2 to 4 inches wide may be removed to the desired depth by means of a hard, stiff putty knife. A hatchet or small hand axe is often convenient to mark out the portion which is to be removed. The first cut is thrown away and the sample taken from the bottom of the hole by means of a putty knife. If any water or dirt is on the surface of the material in the barrel or drum selected for sampling, it should be removed so that the surface is clean and dry. A large sponge will be found useful for this purpose.

116. Sampling from Loose Bulk. When a hard and relatively pure bituminous material such as Gilsonite is shipped

in loose fragments, one sample should be taken for every five or six tons represented by the shipment. The individual samples should be taken from as many different locations as possible in the car or pile. Rock asphalt may be sampled in like manner, except that one sample may be taken for every 40 to 50 tons. Owing to the fact that rock asphalts may congeal more or less during storage and shipment, a pick may be required to obtain samples.

117. Prepared Joint Fillers. At least three samples should be taken of every shipment of bituminous expansion joints or prepared joint fillers. Each sample should consist of a strip about twelve inches in length.

CHAPTER VI

LABORATORY TESTS OF BITUMINOUS MATERIALS

SIGNIFICANCE OF LABORATORY TESTS

118. Value of Tests. Unlike many other road and paving materials, only a few of the laboratory tests for bituminous materials directly indicate suitability for a given purpose, and even these must be considered with special reference to the type of material which other laboratory tests serve to identify. Among the tests indicating suitability, the most important are those which determine consistency. For certain classes of work such tests may often be made by the Inspector (§§ 378–379). In like manner, certain tests are sometimes made which serve as a control for the use of the material but do not necessarily indicate inherent suitability (§ 380). Tests for identification purposes which may be specified are usually made in the laboratory only, but the Inspector should be familiar in a general way with the methods employed in making such tests and the use for which the test results may serve.

119. Specification Requirements. Specification requirements for bituminous materials have not been as generally standardized as for other highway materials and, owing to the many different products which have to be considered as a class, embrace a large number of tests. Some of these tests may be of purely local significance, as they are used and understood only by the Engineer in whose laboratory the test was devised. In general, however, the Engineer,

in preparing specifications, selects from a number of tests which have been widely used, and such tests are briefly covered in the following paragraphs.

120. Temperature Considerations. (*a*) It has been noted (§ 108) that changes in temperature produce marked changes in the volume of bituminous materials and that for the purpose of volume measurements 60° F. (15.5° C.) is taken as normal temperature. Other characteristics of bituminous materials are also affected by temperature, particularly their consistency. For laboratory tests, therefore, it has been thought advisable to adopt a normal temperature which is commonly understood to apply unless some other temperature is specifically mentioned. As applied to laboratory observations of the physical characteristics of bituminous material, the American Society for Testing Materials has adopted 25° C. (77° F.) for normal temperature, Standard Definitions D8–18. This standard is almost universally used.

(*b*) Most specifications state temperature requirements in degrees Fahrenheit, particularly when they apply to field control. The Inspector, therefore, ordinarily uses that scale and is supplied with a Fahrenheit thermometer. The Centigrade scale is, however, generally employed in the laboratory, and specifications for bituminous materials as well as test reports frequently state temperature in degrees Centigrade. In any event it may be necessary for the Inspector to translate from one scale to the other. For this purpose the following formulas should be used:

$$°F = \tfrac{9}{5}°C + 32.$$

$$°C = \frac{5(°F - 32)}{9}.$$

For ordinary purposes the equivalents shown in Fig. 13 will be found sufficiently accurate.

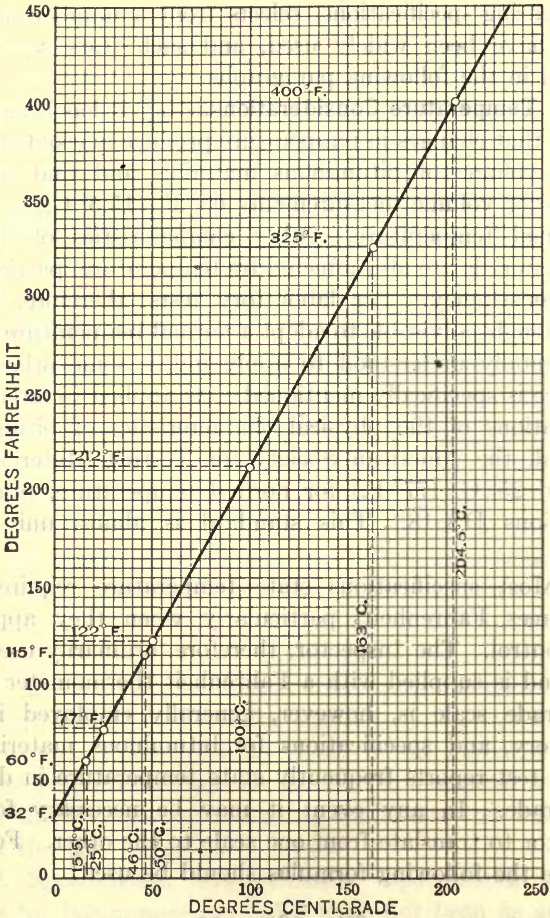

Fig. 13 Equivalents of Fahrenheit and Centigrade Scales

DENSITY TESTS

121. Specific Gravity. (*a*) There are a number of methods used for determining the specific gravity of bituminous materials, depending largely upon their consistency at normal temperature (§ 120*a*). Thus, for thin fluids a hy-

drometer may be employed for obtaining direct specific gravity results. The more viscous fluids and semisolid materials are commonly weighed in a pycnometer or bottle of special design and known capacity. The weight of material divided by the weight of an equal volume of water at normal temperature then gives the specific gravity of the material. For hard solid materials a fragment may be weighed in air and then weighed suspended in water by a thread or fine wire. When this is done, its specific gravity is obtained by dividing its weight in air by the difference between its weight in air and in water. In order that there may be no misunderstanding as to the basis upon which the determination is made test results are frequently reported as in the following example:

Sp. Gr. 25° C./25° C. 1.035

This means that the determination has been made on the basis of the weight of a definite volume of the material at 25° C. as compared with the weight of an equal volume of water also at 25° C. In some few cases such as creosoting oils specific gravity may be determined and reported upon a 38° C./38° C. basis.

(*b*) For liquid materials lighter than water, particularly fluid petroleum products, manufacturers have become accustomed to using an arbitrary scale of specific gravity known as the Baumé scale. For this purpose they make use of a hydrometer graduated in degrees Baumé. Petroleum products for highway work are, therefore, sometimes specified and sold upon a degree Baumé or °B. basis. The Inspector may have occasion to translate direct specific gravity into °B. and vice versa, in which case the following formulas apply:

$$\text{Sp. Gr.} = \frac{140}{130 + {}^\circ\text{B}}$$

$$^\circ\text{B} = \frac{140}{\text{Sp. Gr.}} - 130$$

For ready reference the diagram of equivalents shown in Fig. 14 will be found useful. In this diagram it will be noted that the degrees Baumé decrease as specific gravity increases.

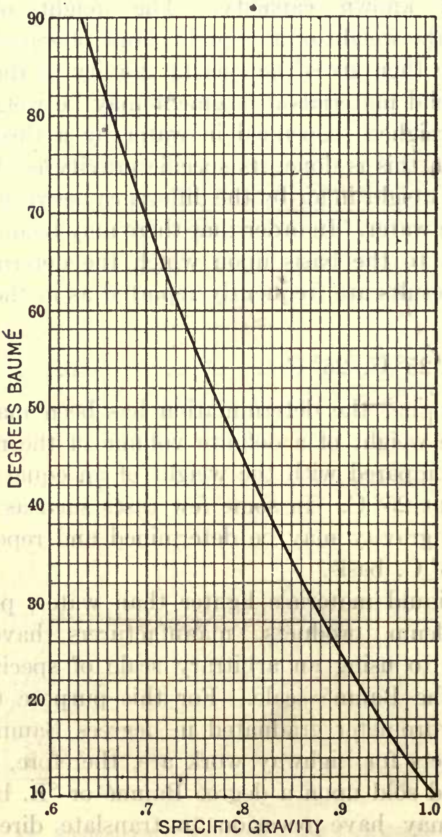

Fig. 14 Specific Gravity Equivalents of Baumé Scale for Liquids Lighter than Water

(*c*) While the Inspector is seldom required to make specific gravity determinations of bituminous materials, he may frequently make use of laboratory test reports to good advantage in estimating correct proportions and in

measuring quantities of materials, as well as amount of work performed. Such uses have already been indicated (§ 107) and will further appear in connection with paving plant inspection and the inspection of various types of highways in which bituminous materials are used. In addition, the specific gravity test is a valuable means of identifying the material, particularly in connection with a test of consistency. It is frequently used in specifications for this purpose as well as for the sake of controlling uniformity of supply from a given source.

122. Coefficient of Expansion. The cubical coefficient of expansion of a bituminous material is seldom specified except for the purpose of making volume corrections for elevated temperatures (§ 108). For this purpose the term "coefficient of expansion" may not even be used, but instead the volume correction which will be made for certain increases in temperature is stated. The coefficient of expansion or volume increase which the material undergoes for each increase of one degree above normal temperature may be stated in terms of the Fahrenheit or Centigrade scale. To translate from one to the other the following formulas apply when K represents the coefficient of expansion.

$$K \text{ per } {}^\circ\text{C.} = \tfrac{9}{5} K \text{ per } {}^\circ\text{F.}$$
$$K \text{ per } {}^\circ\text{F.} = \tfrac{5}{9} K \text{ per } {}^\circ\text{C.}$$

The coefficient of expansion may be determined by heating a known volume of the material at normal temperature to an elevated temperature at which its volume is then noted. The unit increase in volume divided by the number of degrees above normal temperature to which the material was heated gives its coefficient of expansion.

CONSISTENCY TESTS

123. Viscosity. The viscosity, ordinarily expressed as specific viscosity, of liquid bituminous materials is determined by means of the Engler viscosimeter. In brief, this

apparatus consists of a cylindrical cup with a small outlet tube of standard dimensions fitted to the bottom. This outlet tube may be opened or closed with a pointed hard-wood stopper. The cup is jacketed with a water bath for controlling the temperature at which the test is to be made and the entire apparatus is suitably mounted on a tripod so that a measuring cylinder may be placed under the outlet. The test consists in placing a given volume of bituminous material in the cup and bringing it to the proper temperature for test. The outlet tube is then opened and the time required for a given volume of oil to flow into the measuring cylinder is ascertained with a stop watch. The number of seconds is then a measure of the viscosity, or resistance to flow, of the material and test results are sometimes expressed in seconds. It is more customary, however, to divide this time by the time required for the same volume of water at normal temperature to flow through the outlet, the quotient obtained being specific viscosity. Specifications and test reports should always indicate whether results are expressed in seconds or in terms of specific viscosity as well as the measured quantity of material passing the outlet and its temperature. Thus, if the test is made upon a material at 40° C. and 220 seconds is required for 50 cubic centimeters to pass the outlet tube, the test result should be expressed as follows:

Viscosity Engler 40° C., 50 c.c. . . . . .220″

If it is found that 11 seconds are required for the passage of 50 cubic centimeters of water, then results may be expressed as specific viscosity by dividing 220 by 11, thus:

Specific Viscosity Engler, 40° C., 50 c.c. 20

It is evident that as the consistency of a material increases from very liquid toward semisolid, its viscosity or specific viscosity also increases. The viscosity test is widely used for specifying and controlling the consistency of dust pre-

ventives and carpeting mediums. The test itself is ordinarily made in the laboratory and seldom by the Inspector. The temperatures of test most commonly used are 25° C., 40° C., and 100° C.

124. Float Test. The float test is used for determining the consistency of those products which are too viscous for satisfactory use in the Engler viscosimeter and not sufficiently solid for the penetration test. Such products are mainly heavy refined tars used as cements or seal coating materials. The test is most frequently performed in the laboratory, but may be used in the field for important work such as bituminous concrete. It is, therefore, described in detail under Field Tests (§ 379). This test consists in determining the time required for a small plug of the material held in a standard mold which is floated upon water to soften sufficiently at a given temperature to allow water to enter the float and cause it to sink. The test temperatures most commonly specified are 32° C., 50° C., and 100° C.

125. Penetration Test. This test has been adopted by the American Society for Testing Materials as Standard Test D5–16 and is widely used for determining the consistency of asphalts and asphalt cements. It is not only made in the Laboratory, but at paving plants as well and it is, therefore, fully described under Field Tests (§ 378). In the standard test, penetration is defined as "the consistency of a bituminous material, expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. When the conditions of test are not specifically mentioned, the load, time, and temperature are understood to be 100 grams, 5 seconds, 25° C. (77° F.), respectively, and the units of penetration to indicate hundredths of a centimeter." Thus an asphalt cement of 50 penetration is one which at 25° C. will allow a standard needle operating under a weight of 100 grams to penetrate it for a distance of 50 hundredths of a centimeter in 5 seconds.

126. Melting or Softening Point. (*a*) Three methods for determining the melting or softening point of bituminous materials are in common use, the cube-in-air method, the cube-in-water method, and the ring-and-ball method. Results upon the same material by the three methods often differ widely because there is no definite temperature at which an apparently solid bituminous material suddenly becomes fluid. These materials soften gradually with increase in temperature, so that various conditions attending the method of making a test will influence the final result. For this reason the exact method should always be indicated in specifications and test reports.

(*b*) In the cube-in-air method, a ½-inch cube of the material is suspended in air upon a wire 1 inch above the bottom of a glass beaker or jar, which in turn is placed in another beaker of water. A thermometer is also suspended beside the cube of material. The water in the outer vessel is then heated so that the air temperature in the inner vessel increases at the rate of 5° C. (9° F.) per minute, and when the cube softens sufficiently so that it touches the bottom of the beaker the temperature is recorded as its melting or softening point. The cube-in-water method is the same as the cube-in-air method, except that the outer beaker is dispensed with and the beaker containing the specimen is filled with water. The ring-and-ball method is also quite similar, except that the material is cast in a standard ring mold and both the mold and contents are suspended in the beaker beside the thermometer. A standard steel ball or shot, of smaller diameter than the ring, is placed upon the surface of the material before heat is applied. The rate of increase of temperature is the same as in the cube method, and the melting point of the material is ascertained in the same general manner. With the ring-and-ball method, the outer jacket is dispensed with and the beaker containing the specimen itself is filled with water.

(*c*) The melting or softening point of bituminous fillers

and tar pitches is commonly specified and the test is used to some extent on asphalts and asphalt cements for paving work, where it serves to control uniformity of supply and method of manufacture. Blown asphalts usually show a much higher melting point than residual asphalts of the same penetration. The melting point may be specified and reported either in °C. or °F.

127. Ductility. A ductility requirement is often specified for asphalt cements. When such is the case, the test is made by pulling apart a briquette of the material having a minimum cross section of 1 square centimeter and ascertaining the distance in centimeters which it will stretch without breaking. Thus a ductility of 50 indicates that the material will stretch 50 centimeters before failure occurs. The test is commonly made with the material under water at 25° C., the rate of pull being 5 centimeters per minute. Various machines have been devised for this test, all, however, based on the same general principle of producing a steady uniform pull. When subjected to the test, most fluxed native asphalts and asphalt cements produced by careful distillation of asphaltic petroleums pull out to a long thin thread before breaking, while highly blown asphalts, which are characteristically short, rupture without pulling to a thread. For a given type of material ductility decreases with hardness or decrease in penetration.

HEAT TESTS

128. Flash and Burning Points. As determined by test the flash point of a bituminous material is the temperature to which it must be heated in order that the vapors liberated at its surface will flash or ignite when a small flame is brought in contact with them. The burning point is that temperature to which the material must be heated in order to catch fire and burn when a small flame is brought in contact with its surface. For all but extremely volatile products there is usually a considerable difference between

the flash point and burning point temperatures. The test is made in two types of apparatus known as the open cup and the closed tester. As the type of apparatus largely affects the test results, it should be indicated in specifications and test reports. Results obtained with the open cup are usually higher than with the closed cup. Flash point and burning point requirements are used as a means of insuring or eliminating the presence of volatile constituents in the product, as may be desired. Thus a cut-back asphalt for cold surface application may be required to show a low flash point, while a high flash point may be required of an asphalt cement for bituminous concrete. Flash points and burning points may be specified and reported either in ° C. or °F.

129. Volatilization Test. (*a*) The volatilization test, which is commonly applied to petroleum and asphalt products, determines the loss by volatilization which occurs when a given weight of the material, placed in a container of given dimensions, is maintained at a specified temperature for a stated length of time. Such a test has been adopted by the American Society for Testing Materials, as Standard Test D6–16. In this standard a 50-gram sample is tested at a temperature of 163° C. (325° F.) for five hours and the loss by volatilization is expressed as per cent of the original material. Sometimes other temperatures and lengths of tests are specified, and test reports should always indicate just how the results have been obtained. Thus

Loss at 163° C., 5 hours.......................2.7%

(*b*) After a volatilization test has been made the residue remaining is often subjected to one of the tests for consistency and the results obtained compared with the consistency of the original material. The volatilization test then not only indicates how much of a material is likely to evaporate or volatilize at an elevated temperature, but how much it may harden through such loss by volatilization.

Thus, a cut-back asphalt may be required to show a relatively high loss by volatilization with a change from liquid to semisolid consistency, while an asphalt cement or an ordinary flux will be required to show low loss by volatilization and relatively little hardening due to such loss.

130. Asphalt Contents. Closely related to the volatilization test is the determination of the so-called per cent of asphalt. This test is sometimes made upon liquid petroleum residues as a measure of consistency at normal temperature, but it is not a very reliable indication except for certain types of oil. In general, it is made by heating in an open dish a weighed quantity of the material, at a temperature not exceeding 260° C. (500° F.). At intervals the sample is allowed to cool and its penetration taken at 25° C. When the residue shows a penetration of approximately 100 it is weighed. This weight is then calculated to per cent of the original sample and reported as the per cent of asphalt, thus:

Per cent of asphalt of 100 penetration........80%

The test is apt to be misleading, as a fluid, nonvolatile oil may show a high asphalt content but develop little or no binding value in service, while a more volatile fluid product may show a much lower asphalt content but actually produce such asphalt under service conditions so as to develop considerable binding value.

131. Determination of Water. The presence of water in a bituminous material may usually be detected by the foaming which takes place when it is heated to approximately 100° C. (212° F.). The percentage of water is determined by carefully distilling a measured quantity of the material in a special dehydrating apparatus and measuring the water which is caught as distillate.

132. Distillation. (*a*) The distillation test is usually specified for refined tars and has been adopted by the American Society for Testing Materials as Standard Method D20–18. It consists in placing a known volume and weight

of the material in a standard distilling flask, heating the contents gradually and collecting, measuring and weighing the distillates coming over between certain temperatures. The percentage of such distillates may be specified and reported either upon a volume or weight basis. The temperatures which are selected as well as the method of reporting test results are shown in the following example:

Distillate	Per Cent	
	By Volume	By Weight
Up to 110° C.	0.7	0.5
From 110° C. to 170° C.	1.2	0.8
From 170° C. to 270° C.	23.8	19.9
From 270° C. to 300° C.	15.9	14.8
Pitch residue	58.4	64.0
	100.0	100.0

Specifications for cut-back asphalts sometimes require cuts to be made at other temperatures. For distilling creosote oils the American Society for Testing Materials Standard Method D38–18 is commonly used. This method is quite similar to that already described except that a standard retort is used in place of the distilling flask and distillates are collected at 210°, 235°, 270°, 315° and 355° C.

(*b*) As a part of the distillation test the specific gravity of certain distillates and the consistency of the pitch residue may be specified and determined. As applied to tars the distillation test is valuable both as a means of controlling their method of manufacture and suitability for a given purpose. In this connection it takes the place of the volatilization test (§ 129), which is usually restricted to petroleum and asphalt products.

SOLUBILITY TESTS

133. Total Bitumen. The per cent of bitumen in a bituminous material is determined in the laboratory by treating a

weighed sample of the material with carbon disulphide, which dissolves all the bitumen present. The dissolved bitumen is then separated from any insoluble matter by filtration in a suitable apparatus. Any residue is then washed clean with carbon disulphide and after drying is weighed. Its weight subtracted from that of the original sample gives the weight of total bitumen, which is reported upon a percentage basis. The residue may next be ignited to burn off organic matter and, after cooling, again weighed and reported as per cent of insoluble inorganic matter. The amount burned off is determined by difference and reported as per cent insoluble organic matter or, in the case of tars, as free carbon.

(*b*) In the case of bituminous aggregates the insoluble residue after weighing may be subjected to a mechanical analysis to determine its grading. Frequently a special form of extraction apparatus is used for filtering or removing the dissolved bitumen from the nonbituminous aggregate.

(*c*) While the Inspector is not ordinarily required to make determinations of total bitumen, he may frequently have to make use of laboratory reports of same. Thus, if purchase of the material is made upon its per cent of total bitumen, the determination may be necessary as a basis of measurement and payment (§ 106 *c*). It is always necessary as a basis of controlling the proportion of bituminous material which should be used in bituminous concrete or sheet asphalt and is used by the laboratory as a check upon paving plant operations. In connection with specific gravity determinations of the constituents of a bituminous aggregate, it is also valuable as a means of determining the per cent of voids in sections of finished pavements (§ 384).

134. Asphaltenes or Bitumen Insoluble in Paraffin Naphtha. This determination is made only upon petroleum and asphalt products and in specifications is usually limited to residual petroleums. In general the method is the same

as for the determination of total bitumen (§ 133 *a*) except that petroleum naphtha is used as a solvent instead of carbon disulphide. The bitumen of asphaltic products is only partially soluble in petroleum naphtha and that portion which is insoluble is commonly known as asphaltenes. The solubility of any asphaltic product in naphtha varies with the character and specific gravity of the naphtha itself so that certain grades have been selected for the test. The one most commonly used is known as 86° B. or 88° B. (§ 121 *b*) naphtha, although 72° B. naphtha is sometimes used. Test results are reported as per cent of bitumen insoluble and not as per cent of the original material which is insoluble in the naphtha. In general the higher the percentage of asphaltenes present in a petroleum product the more asphaltic is its character and specifications sometimes make use of the test in order to secure a highly asphaltic product.

135. Carbenes or Bitumen Insoluble in Carbon Tetrachloride. This test is made upon petroleum and asphalt products and is reported upon the basis of per cent of bitumen insoluble, in exactly the same manner as described for asphaltenes (§ 134). Most petroleum and asphalt products are equally soluble in carbon disulphide and carbon tetrachloride, but if badly cracked or injured by overheating during manufacture they become less soluble in the latter solvent. The presence of such insoluble bitumen, called carbenes, is sometimes limited in specifications.

136. Dimethyl Sulphate Test. This test is made upon bituminous materials which may be specified or thought to be mixtures of tar with petroleum or asphalt products. It consists first in distilling the material (§ 132 *a*) and collecting distillate fractions from 270° to 300° C., from 300° to 350° C. and from 350° to 375° C. These distillates are then treated with dimethyl sulphate. Tar distillates are completely soluble in this reagent, while petroleum and asphalt distillates are insoluble. Mixtures of the two classes will, therefore, yield distillates which are only partly soluble

and when treated with dimethyl sulphate the insoluble portion separates in a distinct layer.

MISCELLANEOUS TESTS

137. Fixed Carbon. This is an arbitrary test sometimes specified in connection with petroleum and asphalt products. It is made by heating a weighed sample of the material in a covered platinum crucible until all volatile matter is burned off and only residual coke is left. This coke is weighed and after subtracting any ash which may be left after ignition in the uncovered crucible, the results are reported as percentage of fixed carbon upon the basis of bitumen present. The test is not exceedingly accurate and is used mainly as a means of determining the asphaltic character of the product. Thus, products manufactured from paraffin petroleums show little or no fixed carbon, while solid asphalts may show 15 per cent or more. As a rule semiasphaltic products produce less fixed carbon than asphaltic products of the same consistency.

138. Paraffin Scale. At one time specifications for petroleum and asphalt products commonly limited the per cent of paraffin scale which might be allowed. Owing to the inaccuracy of the test and to the fact that such a limitation is not now considered so necessary, if the material meets other requirements, its use has been largely abandoned. When specified, the test is made by rapidly distilling a weighed sample of the material to coke and collecting the entire distillate. A weighed sample of the distillate is then chilled to 20° C. and treated with a mixture of absolute alcohol and ether at the same temperature. Any paraffin scale which is present then precipitates out and is quickly filtered off. Its weight is calculated as per cent of the original sample.

139. Special Tests for Emulsions. Various tests of a chemical nature which are of little direct interest to the

Inspector are sometimes specified in connection with emulsions. The more important tests are the determination of water, determination of total bitumen, distillation, and a test for consistency of the residue obtained by distillation to a given temperature. It is also sometimes required that when the emulsified product is mixed with a certain proportion of water no separation shall occur during a certain period of standing and that when mixed with a clean mineral aggregate the bitumen shall adhere firmly to the surfaces of the mineral particles.

140. Special Tests for Creosoting Oils. Certain special tests for creosoting oils which have not been covered in the preceding paragraphs are sometimes specified. These are of little interest to the Inspector unless he is required to make them at the creosoting plant (§ 322). The most important of these is the determination of solubility of the material in benzol or chloroform. In general, this test is similar to the determination of total bitumen (§ 133) except that benzol or chloroform is used as a solvent instead of carbon disulphide. Filtration or separation of the insoluble material is made in a special type of apparatus known as a hot extractor. Such a method has been adopted by the American Society for Testing Materials as Standard Method D38–18. Other tests which may be mentioned are the determination of tar acids, the determination of naphthalene and the sulphoration test.

CHAPTER VII

INSPECTION OF SAND–CLAY, GRAVEL, SHELL AND SHOVEL–RUN OR CRUSHER–RUN SLAG ROADS

SAND–CLAY AND TOPSOIL ROADS

141. General Characteristics. Sand-clay and topsoil roads are earth roads composed essentially of sand (§ 46) and clay (§ 49) in such proportions as to produce much greater stability under varied seasonal and climatic conditions than is afforded by ordinary earth or soil. In sand-clay roads the mixture of sand and clay may be either natural or artificial. Such mixtures occurring at the surface of cultivated fields are called topsoils. Theoretically, the best mixture consists of a sand body containing just sufficient plastic clay to fill the voids and bind the sand and silt grains together. After compaction such a mixture, when wet, possesses the stability of sand and, when dry, the stability of clay. Under traffic, during rainy weather it does not become as soft and muddy as a clay road nor as dusty in dry weather. The presence of gravel (§ 42) in the mixture is rather desirable than otherwise, as it increases stability or resistance to displacement under traffic. Mixtures containing a considerable amount of gravel are sometimes termed semi-gravel. The relative proportions of sand and clay should, however, remain the same as though no gravel were present. These proportions are approximately two parts of sand to one of ordinary clayey soil. The proportion of true clay (§ 42), however, is considerably less than one part to two of sand (§ 143).

142. Construction Methods. There are three general methods of constructing sand-clay roads, depending upon the character of the original soil and that of available local material. If the original soil happens to be a natural sand-clay mixture, the construction methods are the same as for any other earth road. If not, the following conditions may be encountered.

A deposit of natural sand-clay or suitable topsoil may be available for use on the original soil.

If the original soil is not suitable for admixture with sand or clay, both products may have to be placed and mixed on the road.

The original soil may be such that if mixed with sand or clay a suitable combination may be secured.

In the first case the graded roadbed may be trenched out to suitable width and depth and filled with the natural sand-clay or topsoil, or it may merely be covered with the desired thickness of such material. In the second case, one or more layers of sand and clay are spread separately in the trenched roadbed and thoroughly mixed by means of plow and harrow. In the third case a course of either sand or clay, as may be needed, is spread upon the graded roadbed and mixed with the original soil by plowing into it for a suitable depth (§ 145) and then harrowing all of the loose material. In all cases traffic is usually depended upon to puddle and compact the surfacing material, and until this is accomplished the road should be frequently dragged or shaped with a grading machine. A second plowing and harrowing after the first soaking rain is advisable, and possibly the spreading and mixing of additional clay or sand, as may be indicated by the behavior of the mixture under traffic.

143. Selection of Materials. The selection of materials will ordinarily depend first of all upon the character of the original soil. While some soils are suitable for use in a sand-clay mixture, others are wholly unsuitable. Thus, a clean hard sand or a plastic clay may be used to advantage if the

other constituent of the mix is locally available. A clayey sand or a sandy clay may also frequently be used by increasing the proportion of one or the other constituent. Soils containing a high percentage of silt, nonplastic clay or loam are unsuitable. In such cases natural sand-clay, topsoil, or sand and clay separately should be used. An excess of very fine sand, silt, or loam will produce a mushy road in wet weather, while an excess of lean or nonplastic clay will produce a dusty road in dry weather. With available local material it is not always possible to approximate an ideal mixture and at best no absolutely uniform proportion of sand and clay is likely to be secured. Certain ranges of proportions must, therefore, be allowed in practical work. The first conference of State Highway Testing Engineers and Chemists recommended the following ranges for the material passing a 10-mesh sieve in three classes of mixtures. In these allowances total sand includes silt.

Material	Hard or Class A	Medium or Class B	Soft or Class C
	Per cent	Per cent	Per cent
Clay	9–15	15–25	10–25
Silt	5–15	10–20	10–20
Total Sand	65–80	60–70	55–80
Sand retained on 60-mesh sieve	45–60	30–45	15–30

While conformity with any of these classes cannot well be determined by the Inspector it may frequently be his duty to locate available local deposits of suitable material, in which case he should be familiar with a few simple field tests to serve as a guide in distinguishing between the good and the bad.

144. Field Tests of Materials. (*a*) When inspecting available local deposits of sand or sandy soil, it should be remembered that a hard coarse angular sand free from mica

is most desirable in order to obtain an interlocking of the grains under compaction, thus producing considerable mechanical stability when the grains are held together with a clay binder. Visual examination and the use of a 10- and 50- or 60-mesh sieve (§ 371) will be found useful when comparing various products. Only that portion passing the 10-mesh sieve should receive consideration from the standpoint of a possible sand-clay mix. If much mica is present the product should be discarded as inferior, as even a small per cent of mica seriously interferes with the interlocking of the sand grains.

(*b*) Clays or clayey soils should be examined for their plasticity, resistance to slaking and freedom from mica. Relative plasticity, which is a measure of cementing value, may be determined by mixing the clay with water to the consistency of stiff dough and noting if the product may be easily worked into shapes which it will retain without crumbling. Resistance to slaking is ascertained by sun-drying the molded shapes, then placing them under water and noting whether the product sloughs down slowly or rapidly. A slow-slaking product is preferable to one which slakes rapidly.

(*c*) The relative suitability of natural sand clays and top-soils is indicated by mixing them with water to the consistency of stiff dough and molding them into small spheres of approximately the same size. The spheres should be allowed to thoroughly sun-dry and then examined for shrinkage, which is an undesirable characteristic manifested by the development of cracks. The spheres should next be placed in a shallow pan and covered with water which should be poured in gently. Under this test rapid slaking indicates an undesirable product. If it is desired to ascertain the best combination of sand and clay, a number of mixtures of the available materials should be made, varying from equal parts of sand and clay to six parts of sand and one part of clay. These mixtures should be made into

pastes, molded and tested for shrinkage and resistance to slaking as described above. A record should be made for each mixture and care should be taken that the specimens are properly identified, by means of marks, for the shrinkage test, and relative position in the pan, during the slaking test. In addition to the characteristics of nonshrinkage and resistance to slaking, both natural and artificial mixtures should feel distinctly gritty when rubbed between the hands.

145. Measurements. Depending upon the method of construction which is to be followed as well as upon local custom, measurement and payment may be made upon the basis of cubic yards of surfacing materials used, measured in excavation, loose spread, or after compaction. In any event the Inspector may be required to measure depth and width and at times length. When the work is paid for on the arbitrary basis of cubic yards in accordance with a typical cross section of the road, the computation of quantity is a simple matter. If paid for on the basis of cubic yards of material delivered and excavated from the roadbed, measurements of loose material in place or before placing may be required. This method is not exceedingly accurate, as the volume of loose earth is not a constant (§ 48*c*, § 50*c*). In general, however, a loose sand-clay mixture will compact to about two thirds of its original volume, which means that a loose depth of approximately 12 inches will be required to produce a compacted depth of 8 inches. Three cubic yards loose is then equal to two cubic yards compacted. Upon this basis Fig. 15 shows the cubic yards, loose measure, required to construct each 100 linear feet of road 8 inches thick for various widths. When it is necessary to mix either sand or clay with the original soil, the required depth of plowing of the original soil is also indicated. In this diagram a uniform compacted depth of 8 inches is assumed. For 10 inches compacted thickness all values should be multiplied by 1.25, and for 12 inches compacted thickness, by 1.5.

If a greater thickness is specified for the center than for the sides of a road, the values should be multiplied by a factor determined by dividing the actual end section area by one for the same width 8 inches thick (§ 360). While this diagram will be found useful if properly applied, it should be remembered that the values are only approximate as the

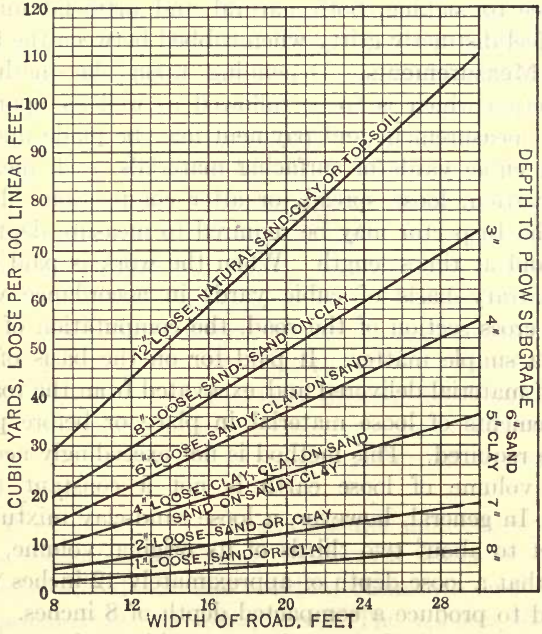

Fig. 15 Quantities of Material Required for Sand-clay Construction

presence of moisture in soil may produce marked differences in volume as compared with the dry soil.

146. Sampling. (*a*) Sand and clay, natural sand-clay and topsoil should be sampled (§§ 59–60) prior to use, and samples of the final mixture before consolidation should also be taken at frequent intervals and tested prior to final acceptance of the work. Each sample submitted to the laboratory should weigh approximately 10 pounds and

should be shipped in a tightly covered pasteboard box, can or close-woven cloth bag.

(*b*) Preliminary samples from the roadbed, if the original soil is to serve as one constituent of the mix, should be taken for a depth of approximately 8 inches every 500 feet of length. Bank deposits of sand or clay to be carried onto the road should be sampled in the usual manner (§ 60*c*). For each acre or less of topsoil two samples should be taken, one a local sample from the center of the area, and the other a composite sample produced by mixing samples taken from a number of points in the area at least 50 feet apart. Samples of topsoil are usually taken for a depth of 8 inches, but this will depend upon the apparent thickness of the soil. All samples should be labeled so as to show the exact location from which they were taken.

(*c*) After the mixture has been spread or prepared upon the road a sample should be taken for each 500 feet of length and its exact location recorded as an item for identification. Additional samples should be taken at any point where reason exists for believing the mix to be unsatisfactory.

147. Inspector's Equipment. Any or all the following equipment may be needed by the Inspector:

For measurements,
- A 50-foot steel tape,
- A pocket rule (§ 387).

For sampling:
- A spade and possibly a pick for sampling natural deposits.
- A garden trowel for sampling on the road.
- A supply of close-woven cloth bags about 12 inches long and 6 inches wide.
- A ball of stout twine.
- A supply of blank eyelet tags for identification information.

For testing:
- A shallow pan about 10 inches in diameter.

A 10-mesh and a 50- or 60-mesh field sieve (§ 371).

A spring balance with pan capacity of 200 grams (§ 371).

For records and reports:

A field diary and pencil.

A supply of report forms (§ 404).

A carbon paper for duplication of reports.

GRAVEL ROADS

148. General Characteristics. Gravel roads may be composed of gravel as obtained from a natural deposit (§ 43), or of the product screened to eliminate certain sizes, or of crushed and screened pebbles. The last mentioned type is similar to the broken-stone road and is constructed in the same manner (§ 163*b*). When the product is not crushed and screened it should be considered as consisting of two principal parts, coarse and fine aggregate, both of which are necessary and should possess certain characteristic properties. The coarse aggregate or material that will be retained on a ¼-inch screen, which is the gravel proper, should predominate and, providing the natural fine aggregate possesses the proper cementing quality, should preferably consist of pebbles of high resistance to wear. These pebbles impart mechanical stability to the road, but as they are usually rounded and will not interlock, must be held in place by the fine aggregate which will pass the ¼-inch screen. The fine aggregate should be present in sufficient quantity to at least fill the voids in the coarse aggregate and should possess considerable cementing value. Cementing value is imparted by clay, limestone or iron hydroxide. When the binder is clay, a natural sand-clay gravel is the best type and as such exhibits the characteristics of a sand-clay road (§ 141), except that it possesses much greater mechanical stability or resistance to displacement under traffic. An excess of clay or of sand in the fine aggregate produces the same general effect as in a sand-

clay road, but to a less extent. In the absence of clay, iron hydroxide serves a similar purpose in certain gravels. If the coarse aggregate is limestone, neither clay nor iron hydroxide need be present, as sufficient calcareous matter will be produced by abrasion to serve as a cementing medium.

149. Construction Methods. A gravel road may be laid directly upon a graded roadbed or in a trenched roadbed in one or more courses. No course should have a finished depth of over 5 inches, as it is impractical to properly consolidate a greater thickness. Courses 3 or 4 inches thick after compaction are to be preferred. The maximum size pebble which is permissible for each course should be specified and should not exceed two-thirds the compacted thickness. The maximum diameter of pebbles in the top or wearing course should not exceed 2 inches, and this will frequently necessitate screening the gravel before use. If there is a deficiency of binding material in the gravel a relatively thin layer of clay is sometimes spread over each course and harrowed in before the course is compacted. If an excess of clay is present sand is worked into the gravel in the same manner for the purpose of obtaining a sand-clay void filler and binder. The gravel should not be dumped on the road in piles from which it is spread out by flattening the piles, as, even after harrowing and rolling, uniform compaction will not be obtained and an uneven surface will ultimately develop. The use of spreading wagons is to be preferred. After spreading, the gravel should be harrowed and shaped. Travel is sometimes depended upon to compact the gravel, but the use of a roller is more customary and is greatly to be preferred. When the cementing material is other than clay the road should be sprinkled just prior to compaction and in very dry weather a light sprinkling may be desirable in the case of a clay binder. After being opened to traffic the road should be watched for the development of depressions or raveling, which should be immediately

remedied by the addition of more gravel or binder and thorough rolling.

150. Material Requirements. The requirements of gravel for a gravel road must of necessity be limited by the characteristics of local material. Thus when clay is the binder, a natural sand-clay gravel is to be preferred. If not locally available, however, a sand gravel or a clay gravel may often be used to advantage if its admixture with the proper proportion of the missing constituent is specified, with the idea of ultimately securing a sand-clay mixture for the fine aggregate. Specifications frequently require that the true gravel fragments be composed of hard durable rock and sometimes an abrasion test (§ 51*a*) requirement is included. Irrespective of the type of cementing material the minimum cementing value (§ 52) of the fine aggregate which will pass a $\frac{1}{4}$-inch screen may be specified. Certain grading requirements are very desirable, but should be so drawn as to allow for a reasonable range of grading. Thus the maximum size of pebble allowable as well as the relative proportion of coarse and fine aggregates may be covered by requiring all of the material upon test to pass a maximum size laboratory screen and a certain minimum and maximum amount to be retained on the $\frac{1}{4}$-inch screen. Both the coarse and the fine aggregates may further be required to show an intermediate grading. As an example, the following grading requirements for gravel for wearing course is briefed from typical specifications of the U. S. Bureau of Public Roads:

Entire Gravel Product	Per cent
Passing 2-inch screen, not less than ..	95
Total retained on $\frac{1}{4}$-inch screen......	50–75
Coarse Aggregate	
Total retained on 1-inch screen......	25–75
Fine Aggregate	
Total passing 200-mesh sieve.........	15–35

Conformity with such requirements may frequently be determined by the Inspector and certain simple field tests may be employed to ascertain the general character of the gravel apart from its grading.

151. Field Tests of Materials. (*a*) When locating available deposits of gravel visual inspection is of considerable service in distinguishing between suitable and unsuitable products. If the face of a gravel bank is exposed and the gravel will stand on a practically vertical slope, a good quality of cementing material in the fine aggregate is indicated. If, on the other hand, the face crumbles readily and develops considerable slope an inferior cementing material is indicated. The soundness of gravel pebbles may be roughly ascertained by breaking a sufficient number with a small hammer. An examination of the faces caused by fracture may enable the Inspector to identify the prevailing rock groups (§ 16) and thus obtain an idea of the physical characteristics which the coarse aggregate possesses. Gravels containing a large proportion of pebbles which break readily, particularly if they are sandstone pebbles, will prove to possess inferior wearing qualities. With a little care in selection and the use of a suitable spring balance (§ 374) the Inspector will be able to determine with considerable accuracy the relative proportion of sound and unsound pebbles in a gravel which is composed of a number of kinds of rock.

(*b*) The grading of gravels should be ascertained and the use of a 2- or 3-inch screen, a $\frac{1}{4}$-inch screen and a 200-mesh sieve (§ 371) will be found of most value. In addition, other screens or sieves may be used to advantage as called for in the gravel specifications. Before discarding a gravel as unsuitable on account of grading, the possibility of making it suitable by admixture with another product such as clay or sand should receive consideration, particularly if the specifications allow for such mixing.

(*c*) When clay is the binding material it may be desirable to test the fine aggregate as for sand-clay mixtures (§ 144).

In such cases a 10-mesh and a 50- or 60-mesh sieve will be needed in addition to those previously mentioned.

152. Measurements. (*a*) In the construction of a gravel road, the gravel is usually paid for on the basis of square

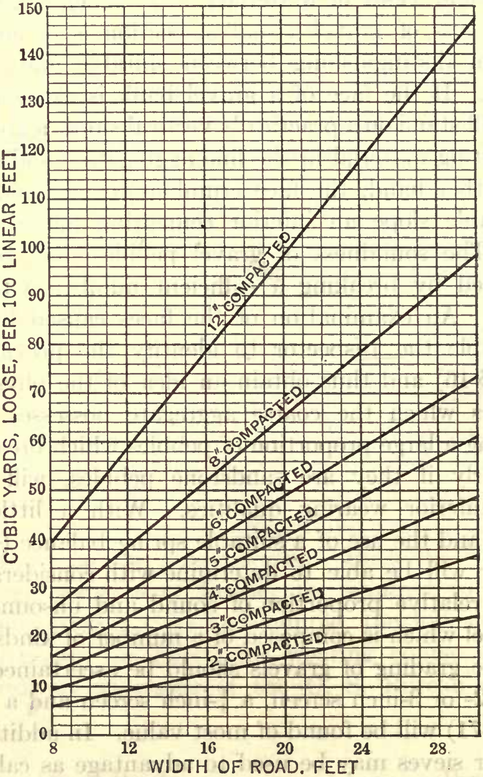

Fig. 16 Cubic Yards of Gravel Required for Gravel Road Construction

yards or of cubic yards of finished gravel road. In such cases, measurements of depth, width and length of compacted material should be made by the Inspector. If specifications have been followed the quantity of material per unit length will then be determined by multiplying such

length by the area of the end section as shown on the plans (§ 360). Sometimes, however, gravel is paid for on the basis of cubic yards or tons delivered on the work. Measurement may then be required in wagons (§ 364) or deposited

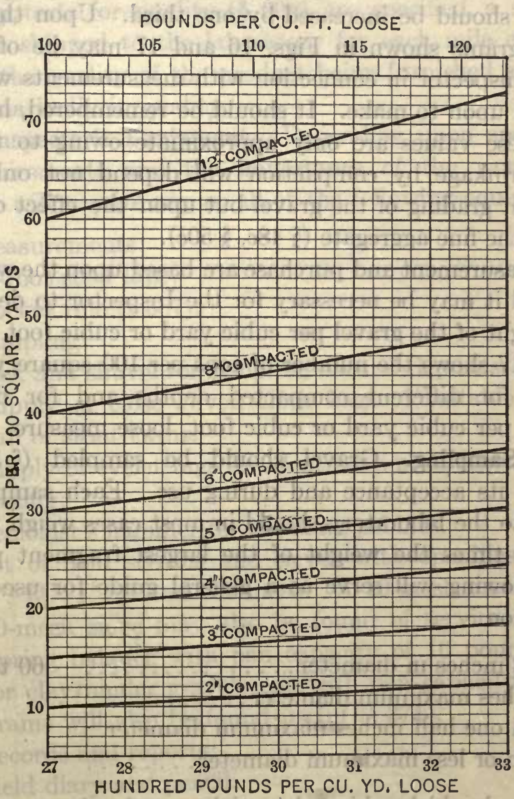

Fig. 17 Tons of Gravel Required for Gravel Road Construction

loose upon the road. In addition, the gravel may sometimes be measured in excavation (§ 362).

(*b*) As used in gravel-road construction, gravel may weigh from 2700 to 3300 pounds per cubic yard, and will shrink from 20 to 30 per cent from loose spread to compacted con-

dition. A shrinkage of at least 25 per cent is ordinarily figured upon when loose measurement is made. This means that when estimating the quantity of loose material delivered from measurements of compacted thickness the compacted volume should be increased by one third. Upon this basis, the diagrams shown in Figs. 16 and 17 may be of service to the Inspector in connection with measurements which he is called upon to make. It should be remembered, however, that these values are only approximate owing to the fact that shrinkage by compaction will depend not only upon the exact grading of the gravel but upon the effect of moisture in the fine aggregate (§ 48*c*, § 50*c*).

If measurement and purchase are based upon the weight of material it may be necessary for the Inspector to determine the weight of the gravel per cubic yard or cubic foot (§ 375). Figure 17 shows the number of tons per 100 square yards of surface for different compacted depths and for different weights per cubic yard or cubic foot, loose measure.

153. Sampling. Gravel should be sampled (§ 59, 60) prior to its acceptance and during use. Each sample submitted to the laboratory should in most cases weigh not less than 50 times the weight of the largest fragment present. The following will serve as a general guide for use in this connection:

Above 2 inches in diameter	60 to 75 lb.
Two inches maximum diameter	40 "
One and one half inches maximum diameter . .	20 "
One inch or less maximum diameter	10 "

Samples should be shipped in tight wooden boxes or close-woven cloth bags.

(*b*) Preliminary samples from natural deposits (§ 60*b*) should be taken as far in advance of acceptance or rejection as practicable. If other than grading tests are required, at least 10 days should be allowed. During use a sample should be taken and tested for grading by the Inspector from each

bulk shipment (§ 60*c*) and if hauled in wagons he should test at least one sample for every 1000 linear feet of road. More frequent sampling and testing will be advisable if the material appears to vary considerably in grading. When laboratory tests for quality (§ 60*a*) are specified, a sample should be shipped to the laboratory for each mile of road or when the quality of the product being furnished appears to vary markedly in quality.

154. Inspector's Equipment. Depending upon specification requirements and the importance of the work, the Inspector will require any or all of the following equipment:

For measurements:
- 1 50-foot steel tape.
- A pocket rule (§ 387).

For sampling:
- A pick and shovel for sampling natural deposits.
- A supply of close-woven cloth bags of suitable size.
- A ball of stout twine.
- A supply of eyelet tags for identification information.

For testing:
- A geologist's hammer for breaking pebbles.
- A set of field screens and sieves with openings of 3″, 2″, $1\frac{1}{2}$″, 1″, $\frac{1}{4}$″ and 200-mesh. A 10-mesh and a 50-or 60-mesh sieve may also be found of service (§ 371).
- A spring balance with pan capacity of 10 pounds and for clay binder gravels one with pan capacity of 200 grams will also be found useful (§ 371).

For records and reports:
- A field diary and pencil.
- A supply of report forms (§ 404).
- A carbon paper for duplication of reports.

SHELL ROADS

155. General Characteristics. Shell roads are constructed like gravel roads (§ 149) in one or more courses. All shells

are composed mainly of calcium carbonate and as they crush easily under compaction produce sufficient fine aggregate to fill the voids between and bind together the larger fragments of shell. While the shells are sometimes spread loose and allowed to compact and bond under traffic better practice calls for shaping and rolling with the use of water and a light covering of sand or sandy soil. Oyster and clam shells are most commonly employed and may be washed or unwashed. If the latter, they are sometimes called mud shells owing to the accumulation of earthy material which they hold after being dredged. Clean shells are often obtained in quantity from canneries.

156. Inspection. Besides visual inspection of quality and usual attention to construction details, the Inspector should

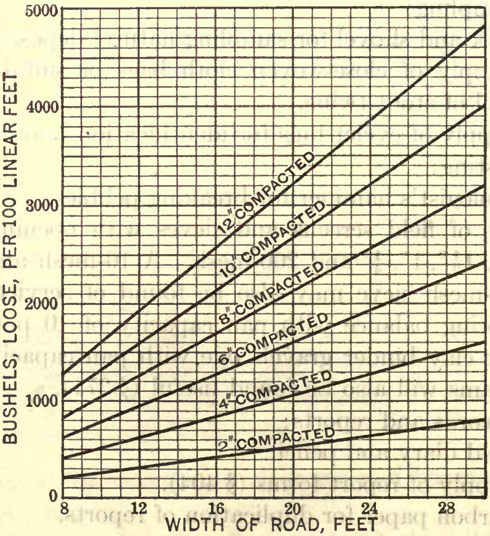

Fig. 18 Bushels of Clean Oyster Shells Required for Shell Road Construction

make necessary measurements of material, as in the case of gravel (§ 152). He will seldom be required to take samples.

Clean shells shrink to about one half their loose volume under compaction and are sometimes purchased and measured upon the oyster bushel basis of $1\frac{1}{4}$ cubic feet per bushel. In Maryland the weight of a bushel of clean oyster shells is set at 57 pounds, which makes 1231 pounds per cubic yard loose, or 2462 pounds compacted. Upon this basis, Fig. 18 shows the number of bushels loose required to construct 100 linear feet of compacted road of various widths and depths. To translate to cubic yards per 100 linear feet, divide the values in bushels by 21.6 or use Fig. 45 by doubling the values for the desired thickness.

SHOVEL-RUN OR CRUSHER-RUN SLAG ROADS

157. General Characteristics. Shovel-run or crusher-run slag should be considered on the same general plane as gravel roads (§§ 148, 149). Blast-furnace slag (§ 168) is commonly used as dug from slag banks with a steam shovel. Sometimes the product is crushed and screened to remove undesirably large fragments before it is placed upon the roadbed. The cementing material is fine slag dust originally present and also produced during compaction.

158. Inspection. Material requirements, field tests, measurement, sampling, and inspectors equipment are much the same as for gravel roads constructed of a limestone gravel (§§ 150–154). A minimum weight per cubic foot is often specified, however, and the Inspector' may be required to determine weight per cubic foot (§ 375) and make use of such determination in estimates of quantities.

MAINTENANCE

159. General Methods. The maintenance of sand-clay, gravel, shell, and shovel-run slag roads consists in filling ruts and depressions with fresh material as used in the original construction. Frequently it is necessary to reshape the road

by means of a drag. When the road is badly out of shape it may be necessary to scarify and harrow the surface to suitable depth, shape the loose material with a road machine or drag, cover with an additional thickness of new material and consolidate the road as in original construction.

160. Inspection. Inspection of maintenance should consist in seeing that the methods specified are followed and that the characteristics of the materials used are as required. Measurements should be made as for construction work. The extent of sampling and testing will depend upon the amount of work and materials involved in the maintenance contract, but in general should be similar to that required for construction.

CHAPTER VIII

INSPECTION OF BROKEN-STONE AND BROKEN-SLAG ROADS

GENERAL CHARACTERISTICS

161. Definition. Broken-stone roads or pavements are those constructed with rock which has been artificially broken or crushed into irregular angular fragments and separated into sizes or commercial grades, each grade containing a preponderance of fragments with certain ranges of diameter. Such products may be manufactured from massive rock, field stone, boulders or gravel. Broken-slag roads are constructed with products produced in the same manner from slag. When no separation of sizes is made and the output of the crusher is used directly in construction, the road should be termed a crusher-run stone or crusher-run slag road (§ 157), to distinguish it from one which has been constructed of a number of sizes or grades of material. When a crusher-run product is used, the methods of construction and inspection are similar to those described under Gravel Roads (§ 149).

162. Types. There are two principal types of broken-stone roads commonly designated as Telford and Macadam. Use of the Telford type is largely confined to the construction of foundations in cases where the natural subgrade or soil conditions are poor and the traffic heavy. The Telford road or foundation is composed of large stone fragments napped to approximately rectangular shape and set close together by hand. The interstices are filled with smaller fragments which are wedged into place by rolling or tamping.

The Macadam type is composed of one or more courses of a definite size, crushed or broken product in which the fragments are interlocked by compaction and in which the surface course, at least, is filled with fine mineral particles and bound together by sprinkling with water and rolling. The term Telford-macadam is frequently applied to a Macadam road with a Telford foundation.

163. General Methods of Construction. (*a*) In the Telford road or foundation the stones should be laid on the subgrade in parallel courses with the broadest face down when their specified dimension for depth is perpendicular to the surface. They should be placed so as to break joints and wedged into position by driving into the interstices small stone fragments of suitable size. All projecting points should be napped off, the surface voids filled with small stone and the road thoroughly compacted by rolling with a three-wheel roller weighing not less than 10 tons. If very irregular, the large stone should be napped into approximately rectangular pieces before laying. A depth of 8 inches after napping is usually specified, while a width of from 2 to 6 inches and a length of from 6 to 12 inches may be allowed.

(*b*) In the Macadam road a specified size (§ 17*c*) of broken stone or slag is first spread on the roadbed to such depth that after compaction it will have the desired thickness. It is then rolled until the fragments interlock and may afterwards be filled with screenings, sand, or sandy soil which is spread and rolled or broomed into the voids. As this course serves as a foundation, the void-filling material is sometimes omitted, but, if used, all excess should be removed from the surface before the next course of stone is spread. A second course of stone which is also of specified size is then spread, interlocked by rolling, and filled with screenings, after which, if it is to serve as a wearing course, the road is well sprinkled and rolled until bonded with the addition of a thin course of screenings which remains on

the surface. The second course is sometimes followed by a third or wearing course, in which case it is constructed in the same manner as the foundation.

IMPORTANT DETAILS OF MACADAM CONSTRUCTION

164. Preparation of Subgrade. The subgrade is usually prepared as a shallow trench of the same width as the broken-stone surface. It is commonly protected by earth or gravel shoulders, but in the case of city streets its sides may be curbs or gutters. It is very important that the subgrade be brought to true line and grade when thoroughly compacted. Bumps, depressions, or ruts in the subgrade will almost invariably appear in the surface of the finished road. The subgrade should be firm and unyielding, so as to possess good and uniform bearing capacity and prevent the first course of broken stone from being driven deeply into it. A natural sand-clay or gravelly (§ 141) soil makes the best type of subgrade. If of a clayey nature it may, therefore, be improved by the addition of sand and if too sandy by the addition of clay. After preparation the subgrade should be kept in such condition as to drain readily, and all soft and yielding material which will not readily compact when rolled or tamped should be removed and replaced with suitable material. It should preferably be rolled with a three-wheel roller weighing not less than 10 tons until no further compaction can be obtained. Sometimes flat-headed spuds are set on the rear wheels of the roller and this aids greatly in obtaining maximum compaction if rolling is continued until the spuds make little or no impression in the surface and the roller wheels ride practically clear. When the compacted depth of broken stone is to be the same for the entire width of road, the subgrade carries the same crown as the finished road. If the depth of stone is to be greater in the center than at the sides, the subgrade may be

flat or may carry less crown. In certain cases, such as the construction of a V-drain foundation, the subgrade will be dished or carry an inverted crown.

165. Spreading the Stone or Slag. (*a*) The first course of broken stone should never be allowed to be spread upon a wet and spongy subgrade nor on one which is rutted. Stone which has been spread under such conditions should be removed and the subgrade condition remedied. The stone should not be dumped in piles upon the subgrade or foundation and spread from such piles, as uniform compaction cannot then be secured, owing to the fact that at the spot originally occupied by each pile the compaction before rolling is much greater than the immediate surrounding area. A bumpy surface condition will, therefore, ultimately result. The stone as delivered may be dumped upon dumping boards from which it is spread by shoveling or it may be shoveled from piles dumped along the side of the road, in which case care should be taken that it does not first become mixed with dirt or foreign materials. Properly designed spreading dump wagons may also be used to place the stone directly on the road as it is delivered. Such wagons are fitted with wide tires and bottoms hinged to the sides or ends so that by partially opening the bottom the stone is allowed to run out upon the road. It may then be spread uniformly over the surface by means of forks. If at any time the subgrade material should become churned up or mixed with the foundation course, such mixture should be removed and, after remedying the subgrade, should be replaced with fresh stone. Care should always be exercised to see that segregation of sizes of a broken-stone product does not occur during spreading.

(*b*) Screenings should be spread by shoveling from piles along the side of the road or from dumping boards. In order to secure a uniform covering of screenings they should be thrown from the shovel with a side swing so as to distribute each shovelful over a considerable area. This

will prevent the screenings from caking in piles upon the surface.

166. Compacting and Bonding the Courses. (*a*) The foundation and intermediate course, if constructed, may be compacted and bonded in exactly the same manner as the wearing course, but sometimes the use of screenings is omitted and the interlocking of the large stone fragments only is depended upon to produce the necessary mechanical stability. If screenings are used, all excess, after filling the voids, should be broomed from the surface in order to allow the succeeding course to tooth in and form a continuous structure.

(*b*) After spreading the large stone, each course should be rolled with a three-wheel roller weighing not less than 10 tons until the fragments interlock and do not creep or wave ahead of the roller. Rolling should begin at the extreme edge, overlapping the shoulder on the surface course, and should be carried parallel to the center line of the roadway. Each succeeding trip of the roller should uniformly lap the preceding rear wheel track until the center line of the road has been reached, after which rolling should be started and continued from the other edge in a similar manner. The number of complete rollings required to thoroughly compact a course will depend upon the thickness of the course and size and quality of stone. It is difficult, if not impossible, to satisfactorily compact a loose thickness of over six inches except in the case of very soft rock. A hard tough rock, such as trap, will require much more rolling than a relatively soft rock such as limestone. If rolling is carried to excess the sharp edges of the stone will be worn away and the fragments become rounded, in which case satisfactory interlocking cannot be secured. This feature should be carefully watched by the Inspector. Until the coarse stone is filled or covered by another filled course, no traffic other than that necessary to bring on new stone should be allowed over the rolled broken stone.

(*c*) Screenings should be rolled in layers just sufficient to cover the large stone, the purpose being to force them into the voids and bind the coarser fragments together. As they are thus worked into the voids additional screenings should be spread until no more can be forced in. The surface should then be well sprinkled with water and rolled, the operation of sprinkling and rolling being continued until a slight wave of grout is pushed along the surface ahead of the front wheel of the roller. After the top course is compacted and puddled in this manner, it should be covered with a thin layer of screenings and allowed to dry out before being opened to traffic.

MATERIALS

167. Rock. Rock for waterbound broken-stone roads, particularly the wearing course, should preferably possess good resistance to abrasion (§ 28), high toughness (§ 29), and high cementing value (§ 31). As a matter of economy selection is, however, generally restricted to the use of the most available rock which possesses reasonably satisfactory properties, and specifications for quality usually include only a percentage of wear or French coefficient of wear requirement. Experience has shown that certain kinds of rock such as granite, gneiss (§ 21), sandstone, quartzite (§ 22), schist, shale, and slate (§ 26) are not as a rule suitable for this type of construction and their use is frequently excluded by specifications. The Inspector should, therefore, be able to identify them. Granite, gneiss, sandstone and quartzite are, however, sometimes allowed to be used in the lower courses and even in the wearing course if limestone or other cementitious screenings are used for binder. A French coefficient of 7 is usually considered a minimum requirement for wearing course stone and 5 for foundation course. For heavy traffic roads higher limits may be set if the rock is available. Trap rock usually possesses desir-

able qualities, but requires considerable traffic to produce sufficient fine material by abrasion to replace the original screenings as they are removed from the surface and thus maintain the bond. Unless conditions are favorable trap rock roads are, therefore, more apt to ravel than those constructed of limestone, which, while less resistant to wear, possesses a higher cementing value. Soft limestone, on the other hand, will produce a more dusty surface in dry weather. Granites, gneisses, sandstones and quartzite are usually lacking either in toughness or cementing value. In the first case, the larger fragments break up under rolling and traffic and in the latter they do not properly bond when puddled and rolled. When a broken-stone road is to be covered with a bituminous mat or carpet the cementing value of the rock becomes a much less important factor, and due allowance for this fact should, therefore, be made in specification requirements.

168. Slag. (*a*) Slags may be considered as artificial rock resulting as a by-product in the reduction of metallic ores. Their chemical or mineral composition differs materially from that of rock, however, although many of the denser varieties closely resemble natural rock in appearance and structure. Apart from composition, the physical structure, and, therefore, the physical properties of slags are greatly influenced by conditions under which they are allowed to solidify and cool from their original molten state. If these conditions are not uniform, slag from the same bank may vary from a hard, tough, dense mass to a porous friable product and even to fine dust. Unless exceptional care is exercised in the production of broken slag for highway work, the product will be more variable in quality than broken stone.

(*b*) The slags of greatest interest in road construction at the present time are those produced in the reduction of iron ore, and of these the product obtained from blast furnaces is the one produced in greatest quantity and most

widely used. Other products, such as open hearth iron slags and copper or lead slags are sometimes utilized, but at the present time are of relatively minor importance. Most blast-furnace slags are rich in lime, and, therefore, possess excellent cementing value. They usually have a semi-crystalline structure and vary from light to dark gray in color. Individual fragments frequently show a large amount of glassy material and a more or less porous structure.

(*c*) As used in highway work, blast-furnace slags are usually obtained from large banks, where they have been dumped in a molten or semi-molten, condition, after removal from the furnace, and allowed to slowly air cool. Water cooling or any other rapid method is apt to produce a granular or porous product. Some engineers consider it highly desirable that the slag be exposed to the weather and age in the bank a considerable period in order to allow all rapid disintegration which may take place to occur before it is used, and specifications sometimes require such weathering. For water-bound roads, the physical requirements of slag are similar to those specified for rock except that, in addition to a minimum French coefficient of wear (§ 28), a minimum weight per cubic foot is also commonly specified. The latter property may have to be determined by the Inspector in the field (§ 375). For macadam construction a minimum weight of as low as 55 or 60 pounds per cubic foot is sometimes set. In addition, the slag may be required to show a reasonably uniform density and quality and freedom from metallic iron. Slag banks are usually excavated by means of a steam shovel and the slag is crushed and screened in the production of broken slag in the same manner as rock (§ 17). The shovel-run or crusher-run product is sometimes used directly in the construction of roads (§ 157).

169. Sizes of Commercial Products. (*a*) The size or grading of broken stone (§§ 17*c*, 18*c*) or broken-slag products used in waterbound roads is a matter badly in need of standardization owing to unnecessary variations in specifi-

cation requirements as a whole. In general, fragments of a larger size are required for the foundation than for the wearing course proper, although in the case of soft rocks this relation is sometimes reversed or else the same product is used for both courses. It is usually desirable to utilize as nearly as possible the entire output of the crusher from a certain size down and, therefore, to use the individual sizes in the relative proportion that they are produced. Three and sometimes four different sized products are frequently specified when the road is to be built from foundation up. If the road is constructed in three courses, the same size product is frequently used for two of the courses. In general, the maximum size of fragment should not exceed two thirds the thickness of the loose course.

(*b*) As an illustration of size and grading requirements for broken stone to be used in the construction of a two-course road, the following limits from typical specifications of the U. S. Bureau of Public Roads may be cited. These requirements are based upon actual screen tests which may be made in the laboratory or in the field (§ 371).

	Per cent
Bottom or Foundation Course Stone	
Passing 3-inch screen, not less than	95
Total passing $2\frac{1}{2}$-inch screen	25–75
Retained on 2-inch screen, not less than	85
Top Course Stone	
Passing 2-inch screen, not less than	95
Total passing $1\frac{1}{2}$-inch screen	25–75
Retained on 1-inch screen, not less than	85
Screenings	
Passing 1-inch screen	100
Total passing $\frac{1}{4}$-inch screen	40–80

Such products may be obtained by the utilization of a commercial revolving screen with sections containing circular openings of 3″, 2″ and 1″ in diameter. A dust jacket may also be required if the rock is soft and produces an excess of

dust. For an average rock, a bottom course of 5 inches and a wearing course of 3 inches in thickness will utilize practically the entire output of a crusher and provide sufficient screenings to properly bond the surface with a slight excess of screenings, in the case of the softer grades of rock, which may, if desired, be used in filling the bottom course. For a foundation course or for the construction of the entire road, in case it is desired to have large fragments in the wearing course, the entire product between 3″ and 1″ may be used, providing each course is at least 4 inches thick. In such case, the requirement for screenings would be the same and for coarse broken stone or broken slag as follows:

	Per cent
Passing 3-inch screen, not less than	95
Total passing 2-inch screen	25–75
Retained on 1-inch screen, not less than	85

170. Field Tests. (*a*) The Inspector cannot be expected to test the quality of rock for broken-stone roads, but he should be able to identify the principal rock groups (§§ 17–27) and be familiar with their characteristic properties, especially if specifications eliminate certain rocks by name. The rock to be used under a given contract is usually approved upon laboratory tests made in advance of the work, in which case the Inspector will find it convenient to secure a specimen, from the sample tested, to visually compare with material furnished on the job. In the case of slag products, which usually show a greater variation in appearance and characteristics of individual fragments, a comparison sample is of little service, but determinations of weight per cubic foot may be made from time to time by the Inspector (§ 375) to ascertain if specifications are being complied with and also to check the uniformity of the product. Both broken-stone and broken-slag products should be watched to see that they do not contain an excess of thin or elongated pieces, disintegrated or weathered fragments,

dirt or other objectionable material. Any filler, other than screenings, which is allowed to be used should not become sticky when wet, and if soil is used it should be examined for this characteristic by mixing a small amount with water.

(*b*) The size or grading of broken-stone and broken-slag products should be determined for conformity with specification requirements, and a set of selected field screens (§ 371) from the maximum diameter to $\frac{1}{4}$ inch will be found useful for this purpose.

171. Measurements. (*a*) Broken-stone and broken-slag roads are usually measured and paid for on the basis of square yards of surface in place which, for the specified depth, is equivalent to a compacted cubic yard basis with no allowance for extra thickness or material lost by being forced into the subgrade. Measurements of length, width, and depth of compacted material should, therefore, be made by the Inspector. As a check upon this and also when material is paid for upon a cubic yard or ton basis, measurements of loose depth and of quantities by volume or weight (§§ 35–37) of material in cars or wagons is advisable. In Telford construction the actual depth of the large stone should be measured occasionally.

(*b*) Loose-spread commercial sizes of coarse broken stone or broken-slag products contain approximately 45 per cent voids, and compacted by rolling about 30 per cent voids (§ 37*b*). Shrinkage from loose spread to compacted thickness, therefore, amounts to a little less than 22 per cent or to about four fifths of the loose depth. This means that 5 inches of loose-spread rock will compact to about 4 inches. A somewhat greater shrinking will result if the stone is laid directly upon a subgrade which is not composed of good material thoroughly compacted. Theoretically, about 0.3 cubic yard of compacted filler would be used to fill the voids in one cubic yard of compacted broken stone, and this would amount to somewhat over .37 cubic yards loose. Filler for foundation or intermediate course may, however, safely be

assumed as not over .35 cubic yards loose measure for each cubic yard of compacted broken stone. For the surplus of screenings allowed to remain on the wearing course, about

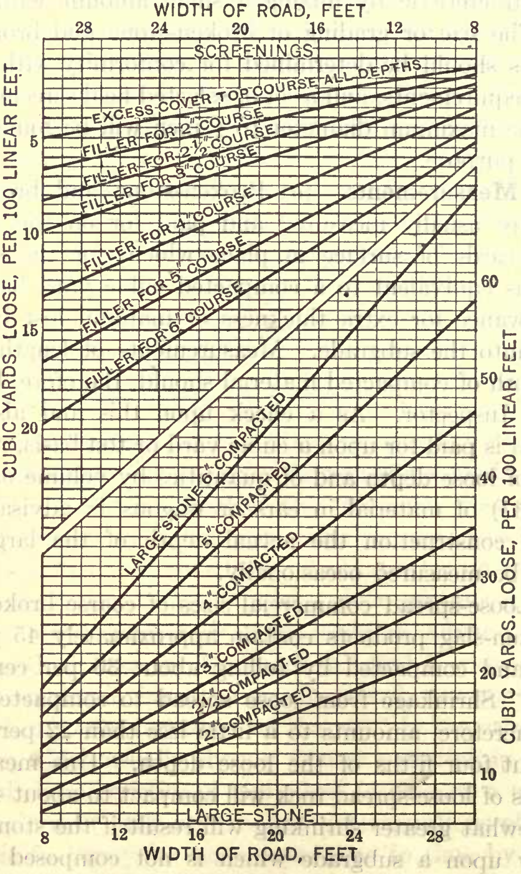

Fig. 19 Quantity of Broken Stone Required for Macadam Construction

.015 cubic yards loose per square yard of surface will be required. Upon this basis Fig. 19 shows the number of cubic yards, loose measure, of coarse stone and filler or screenings

required to construct 100 linear feet of various widths for compacted courses of different thickness.

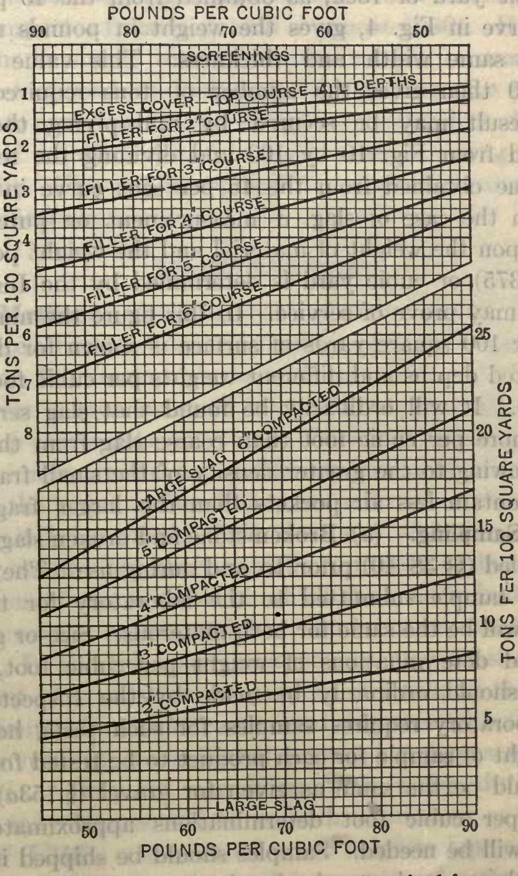

Fig. 20 Quantity of Broken Slag Required for Macadam Construction

As applied to broken stone this diagram may be used in connection with the 45 per cent void curves in Figs. 4 and 5 in determining the number of tons used or required, providing the specific gravity of the rock is known. Thus the

number of cubic yards required for a given width and thickness, as determined from Fig. 19, multiplied by the weight per cubic yard of rock, as obtained from the 45 per cent void curve in Fig. 4, gives the weight in pounds required for the same width and thickness. This value divided by 2000 then gives the number of tons required. The same result may be secured by multiplying the value obtained from Fig. 19 by 100 and dividing the result by the value obtained from the 45 per cent curve in Fig. 5.

(*c*) In the case of slag, if measurement or purchase is based upon the weight of material and the weight per cubic foot (§ 375) or cubic yard is determined by the Inspector, Fig. 20 may prove of service. In this figure the number of tons per 100 square yards of surface is shown for different compacted depths and different weights per cubic foot loose measure. It will ordinarily be found that slag screenings weigh more per cubic foot than coarse slag from the same source, owing to the greater density of the small fragments which contain less air pockets than the larger fragments.

172. Sampling. (*a*) Broken stone and broken slag should be sampled (§§ 38–40) prior to and during use. The weight of each sample submitted to the laboratory for tests of quality will be the same for both materials. Size or grading tests and determinations of weight per cubic foot, if required, should ordinarily be made by the Inspector. If the Laboratory requires samples for such tests, however, the weight of sample for each product to be tested for grading should be the same as given for gravel (§ 153*a*). For weight per cubic foot determinations approximately 100 pounds will be needed. Samples should be shipped in tight wooden boxes or heavy burlap bags. For size or grading tests the sample bags should be close woven.

(*b*) Preliminary samples of rock from the quarry or crushing plant should be taken at least two weeks prior to acceptance or rejection. Preliminary samples of slag should be taken from the crusher or that portion of the bank which

it is proposed to use, at least two weeks and not more than one month prior to acceptance. During use at least one sample of stone or slag should be taken and tested for size by the Inspector from each bulk shipment (§ 40). If hauled in wagons he should test at least one sample for every 1000 linear feet of road, and whenever the grading of a product appears to vary markedly. Weight per cubic foot determinations, if required, should be made when sampling for size or grading. This applies to each size of product covered by the specifications.

MAINTENANCE

173. Methods. (*a*) The cover of screenings on a newly constructed broken-stone road serves only as a temporary protection for the top course while the latter is seasoning. This cover is soon removed by traffic and the large stones of the top course take the wear. The ideal macadam should produce under traffic just sufficient fine products of wear to bond the larger surface fragments and replace the original filler as it is removed. This does not always occur and raveling results, together with the formation of bumps and depressions if the material of which the road is built is not uniform or the entire road has not been constructed uniformly. In the first case, maintenance may consist in the treatment of a road for the purpose of retaining the necessary amount of fine surface material, together with the addition of screenings, if a sufficient amount is not present before treatment. Frequent sprinkling with water during dry periods may be resorted to or such substances as calcium chloride (§ 348), concentrated waste sulphite liquor (§ 350), oil or tar (§ 182), may be used for superficial surface treatment. If a mat or carpet (§ 183) of artificially bound fine aggregate is placed upon the road and such mat removed as it wears away, the coarse stone of the original macadam is not subjected to external wear, so that the original macadam is not maintained as such.

(*b*) Holes, depressions, and ruts are usually remedied by filling with fresh material similar to that of which the wearing course is constructed. Such material should be compacted and bonded by rolling or tamping while puddling with water. Unless such places are first cut out so as to produce excavations with approximately vertical sides to a depth somewhat greater than the maximum diameter of stone used for repairing, the repairs are apt to be unsatisfactory, as the stone will tend to be squeezed out under traffic. Sometimes repairs are made with the addition of a cold patching bituminous binder such as emulsified asphalt or cut-back tar (§ 333).

(*c*) If the road is badly out of shape or has worn away to a considerable extent, maintenance may consist of resurfacing. If a new surface of three or more inches of loose spread rock is to be constructed and the old road surface is in reasonably fair condition, the stone may be laid directly upon the old road, from which all excess dirt and dust have been removed by brooming. When less new material is to be added or the original road is badly out of shape it should first be lightly scarified, harrowed, and reshaped with a road machine. After laying the new stone, all of the loose material is then compacted and bonded as in original construction.

174. Inspection. Inspection of maintenance should be similar in character to that required for construction. The extent of sampling and testing should depend upon the amount of work and materials involved. When, however, maintenance involves surface treatment with bituminous or other materials, additional inspection (§§ 190–191) will be required.

INSPECTOR'S EQUIPMENT

175. Telford Roads. For Telford construction the following equipment is all that the Inspector will ordinarily require:

For Measurements:

A 50-foot steel tape.
A pocket rule (§ 387).

For Records and Reports:

A field diary and pencil.
A supply of report forms (§ 404).
A carbon paper for duplication of reports.

176. Macadam Roads. For macadam construction the Inspector will require the same equipment as for Telford (§ 175). In addition, however, he should be provided with any or all of the following equipment:

For Sampling:

A supply of burlap or close-woven bags.
A ball of stout twine.
A supply of eyelet tags for identification information.

For Testing:

A hand sample of approved rock for visual comparison in the case of broken-stone roads. A small pocket magnifying glass will also frequently prove useful.
A set of field screens and sieves with suitable openings as may be covered in specifications for size (§ 169*b*). Openings of 3″, 2″, $1\frac{1}{2}$″, 1″ and $\frac{1}{4}$″ are suggested (§ 371).
A spring balance with pan capacity of 10 pounds (§ 371).
A cubic foot measure for determining the weight per cubic foot of broken slag (§ 375).

CHAPTER IX

INSPECTION OF BITUMINOUS SURFACE TREATMENTS

GENERAL CHARACTERISTICS

177. Definition. Bituminous surface treatment consists in the superficial application of bituminous material to a road surface which may or may not be followed with a relatively thin covering of stone or slag chips or screenings, fine gravel, sand or other earthy material. Such treatment used in completing the construction of bituminous macadam or bituminous concrete pavements and forming an essential part of such construction is called seal coating and is considered under these types of pavements.

178. Types. There are two general types of surface treatment, that in which the material is applied primarily as a dust preventive and that in which it is applied primarily for the purpose of constructing a thin bituminous mat or carpet upon the road surface. In the latter case, application of the bituminous material is followed with a cover of mineral matter, while in dust prevention this cover is usually omitted. The use of a dust preventive proper does not produce a new wearing surface, but merely reduces the formation of dust and tends to hold in place the fine material on the road surface. The old road surface, however, continues to take the wear of traffic. When a bituminous mat or carpet is constructed, a new wearing surface is produced which itself takes the direct wear of traffic and protects the underlying original road surface. Dust preventives are used in treating earth, gravel, shell, broken

stone and slag roads. Carpeting mediums are used on all of these but the earth road and, in addition, sometimes on Portland cement concrete pavements. Bituminous carpets over one half inch thick are apt to shove or rut under traffic and for this reason the rate of application of bituminous material and cover should be carefully covered in specifications.

IMPORTANT DETAILS OF SURFACE TREATMENT

179. Preparation of Road Surface. (*a*) The condition of the road surface just preceding application of a bituminous material is an extremely important matter which should be given close attention by the Inspector. No surface treatment should be depended upon to eliminate ruts, pot holes, depressions, bumps or waves in the original road. In fact, such faults are more apt to be accentuated by surface treatment. The first consideration, therefore, is to see that all surface irregularities in the road are remedied and that where additional stone, slag, gravel, etc., are used such repairs are thoroughly consolidated before the bituminous material is applied. In some cases the entire surface may have to be reshaped by scarifying, harrowing, bonding and rolling before surface treatment is given. In such cases, as well as in the treatment of a newly constructed road, it is advisable to let the finished surface season for a few weeks under traffic before applying the bituminous material.

(*b*) The second important detail to be observed is that the road surface is as clean and free from dust as possible. In the case of earth roads, little can be done other than to shape and consolidate the surface. Broken-stone, slag, gravel and shell roads should, however, be broomed to remove all excess fine material, care being taken not to disturb the bond betwen the coarser fragments. When the surface is well bonded a mechanical sweeper may often be

used to advantage, but such sweeping is rough and, for surfaces more readily displaced, hand brooming may be required. In either case, the upper surface of the coarse fragments should be exposed so as to produce a granular mosaic surface for treatment. In the case of concrete pavements, the surface should be freed from excess mortar which by breaking up under impact will destroy the bond between the bituminous material and the road, thus promoting disintegration.

(*c*) A third important point to be observed is that the road surface should be thoroughly dry when application of any hot bituminous material is to be made. For cold surface treatments, the surface may be very slightly moist, but never wet. A wet surface may result in absolute failure due to the prevention of any bond being produced between the road proper and the bituminous material.

180. Application of Bituminous Material. (*a*) Distribution of bituminous materials in surface treatment is usually made by means of a tank distributor which may operate by gravity or pressure. Hand-pouring pots are also used to a very limited extent. The most important features to be observed, in connection with the actual application, are uniformity of distribution at the proper rate per square yard, distribution under suitable atmospheric conditions, and in the case of heated materials application at the proper temperature. All of these factors should be covered by specification requirements.

(*b*) Hand pouring should always be followed by brooming the material on the road surface so as to shove ahead all excess. The same is true when a gravity distributor is used except in case of treatment with a very light dust preventive. Most uniform distribution will be obtained by the use of a properly designed and operated pressure distributor. These are ordinarily equipped with spraying nozzles so spaced as to coat a considerable width of surface upon a single trip of the distributor and so controlled that multi-

ples of a given width may be treated. The pressure at which such machines operate efficiently is usually from 20 to 75 pounds. They should be equipped with an accurate pressure gauge and a stationary thermometer to register the temperature of heated materials. Rate of application is usually controlled by the speed of the distributor and flow of material to the nozzle. Any excess of material which accumulates on the road, due to failure to start the distributor promptly when the flow is started, or failure to shut off the flow promptly when the distributor stops, should be broomed off of the surface. Clogging of one or more nozzles sometimes occurs during application, causing bare spots to appear on the road surface after passage of the machine. Just before the tank is emptied portions of the surface may also fail to receive treatment. In such cases the condition may be remedied by hand pouring and brooming the bare spots.

(*c*) When treatment is made with a carpeting medium it is important that the road surface should not be so cold as to prevent adhesion of the bituminous material to the surface. To cover this feature specifications sometimes provide that when application is made air temperature in the shade shall not be lower than 10° C. (50° F.). The proper temperature to heat a material intended for hot application will depend upon a number of factors, but from 200° to 250° F. is usually a safe working range.

(*d*) Bituminous surface treatments usually consist of a single application of from 0.1 to 0.5 gallon of bituminous material per square yard. When, however, it is desired to use a heavy tar or asphalt product on roads from which all dust and fine material cannot be removed, such as clay gravel roads, the treatment sometimes consists of two applications. The first application may then be made with a thin fluid product applied cold, which is absorbed by the road surface and serves as a primer for a more viscous product, which is next applied in a heated state.

181. Application of Mineral Cover. (*a*) When it is desired to build up a bituminous mat or carpet upon a road surface, or when the character and rate of application of the bituminous material are such that it is likely to adhere to the wheels of passing vehicles and be stripped from the surface, a thin cover of fine broken stone, gravel, or similar material is spread upon the treated surface before it is opened to traffic. In general, this cover should be reduced to the minimum required to blot up the excess of bituminous material which has not been absorbed by the road surface. Too heavy a cover is frequently applied, in which case, after being ground up under traffic, the bituminous mat produced is overloaded with mineral matter and soon crumbles and wears away. It is far better practice to at first apply too little cover and then after traffic is admitted on the road to promptly spread additional mineral matter where its need is indicated. Over one cubic yard of mineral matter will seldom be required for each 25 gallons of bituminous material applied, and frequently less may be used to advantage, particularly if the surface is finished off by rolling.

(*b*) Mineral cover is ordinarily spread from piles placed along the sides of the road. Small mechanical distributors have been designed for this purpose, but their use is usually limited to seal coat work (§§ 198, 267, 272) in bituminous macadam or bituminous concrete construction. Cover should be distributed as uniformly as possible and when spread with shovels a wide side swing will be found most efficient. In case of double application involving the use of a primer, cover is sometimes used only after the second application of bituminous material. If spread over the priming material, it should be used in barely sufficient quantity to prevent the distributor wheels from picking up the surface during the second application.

(*c*) Traffic is usually depended upon to force the cover into combination with the bituminous material, but rolling

is highly advantageous in constructing a bituminous carpet where as much as 0.5 gallon of bituminous material is applied per square yard of surface.

MATERIALS

182. Dust Preventives. Bituminous dust preventives are, as a rule, relatively thin fluids which may be applied without preheating. The types commonly encountered are crude or topped (§ 95) semi-asphaltic petroleums, heavy petroleum distillates (§ 94), petroleum emulsions and emulsifying oils (§ 99) and crude or dehydrated tars (§ 102). They should be susceptible to a light uniform distribution so as to saturate the dust particles on the road, but not penetrate the road surface to any extent. They need not necessarily possess or develop cementitiousness, as their function is not primarily that of a binder. To be of maximum service, they should not volatilize rapidly to any extent under ordinary atmospheric conditions. Almost any sufficiently fluid petroleum may be used as a dust preventive, and no test requirements other than maximum viscosity and low loss by volatilization are of importance except as a means of identification. A maximum specific viscosity (§ 123) at 25° C. of 10 and a maximum loss by volatilization (§ 129) at 163° C. of 15 per cent is used to cover these requirements by the U. S. Bureau of Public Roads. Petroleum emulsions are sometimes prepared from the heavier non-volatile petroleum residues for use as dust preventives. Emulsions, or emulsifying oil produced as an alkaline sludge in the treatment of petroleum distillates, can be reduced to any desired viscosity by mixing them with the proper amount of water. The former may even contain an appreciable amount of water as manufactured. Tar dust preventives should not carry over 5 or 10 per cent of free carbon (§ 101*c*) or show a specific viscosity at 40° C., of over 13. As they volatilize or harden more rapidly than petroleum products,

they do not prove effective as dust preventives for as long a period after application.

183. Carpeting Mediums. (*a*) Bituminous carpeting mediums are usually more viscous fluids than are the dust preventives and may be applied with or without preheating according to their viscosity at normal temperature. While it would be desirable that they possess approximately the same consistency as soft bituminous cements, it is necessary that they be more fluid so that they will adhere to a previously untreated road surface. They should, however, possess, or develop shortly after application, sufficient cementitiousness to bind together and hold in place the mineral cover. If they contain a highly cementitious base they may well carry a relatively high percentage of volatile constituents which, after application, will rapidly evaporate and leave practically a bituminous cement in place. This is particularly true of those products which are intended for cold application. The carpeting mediums in most common use are heavy crude, topped (§ 95), or residual asphaltic petroleums, cut-back asphalt cements (§ 98), and fluid residual or refined tars (§ 102).

(*b*) For cold surface treatment the petroleum carpeting mediums (§ 95*b*) should preferably show a specific viscosity (§ 123) between 80 and 120 at 25° C. In order to develop a highly cementitious residue their loss by volatilization (§ 129) at 163° C. may be allowed to be as high as 30 per cent. The residue so obtained should, however, show a float test (§ 124) at 50° C. of not less than 90. Because the presence of a very light flux is desired, cut-back asphalts may be required to show a loss by volatilization at 163° C. of between 30 and 40 per cent and to yield a residue with a penetration at 25° C. of from 50 to 85. Their specific viscosity is usually specified to be lower than for the residual petroleum products because through handling before use ordinary loss by volatilization may cause a material increase in viscosity. For cold surface treatment the specific

viscosity at 40° C. of tars should not exceed 35 and may be as low as 10 or 12. Their percentage of free carbon (§ 133) should not exceed 10 or 15 per cent.

(c) Petroleum products for hot application should preferably show a float test at 32° C. of not less than 60″, but their specific viscosity at 100° C. may be specified as less than 60. Their allowable loss by volatilization at 163° C. may be as high as 15 per cent. Tars for hot application should preferably show a float test at 32° C. between 60 and 150 seconds, and their percentage of free carbon should not exceed 15 per cent. All materials for hot application should be free from water. When a cold primer is to be applied just prior to a hot application, such products as described under dust preventives may be used for first application. It is customary, however, to use a petroleum product as primer for petroleum carpeting mediums and a tar primer when it is to be followed with a tar carpeting medium.

184. Mineral Cover. (*a*) For the construction of bituminous carpets the mineral cover should preferably consist of clean, hard and tough broken slag, broken stone or gravel. No laboratory test for quality is usually required, but size or grading of the product should be specified. Typical specifications of the U. S. Bureau of Public Roads require at least 85 per cent of the product to pass a $\frac{1}{2}$-inch laboratory screen and at least 85 per cent to be retained on a $\frac{1}{4}$-inch laboratory screen. Sometimes a coarse broken stone product is allowable, particularly if the rock is not extremely tough. In such cases the U. S. Bureau of Public Roads' typical specifications require a product at least 95 per cent of which will pass a 1-inch laboratory screen and at least 85 per cent be retained on a $\frac{1}{4}$-inch screen. Sometimes sand or sandy soil may be used for cover if the carpet is to be kept below $\frac{1}{4}$ inch in thickness. The use of a clay or clayey soil should not be allowed, as the carpet when wet will then tend to emulsify under traffic and produce an undesirable surface.

(*b*) While the ultimate maximum diameter of fragments used for cover should not exceed the average thickness of carpet, rolling and traffic tend to rapidly crush the larger fragments. A cover of broken stone of one inch diameter cannot be spread so as to blot up the bituminous material unless an excess is used. Rolling is, therefore, particularly desirable after such a coarse cover is used.

185. Field Tests. The Inspector has but little to do in the way of making field tests when inspecting bituminous surface treatments. He is not expected to test bituminous materials for quality although when purchase is made mainly upon a specific gravity or degree Baumé basis he may possibly be required to make a test (§ 383*a*) on a sample from each treatment. When the bituminous material is to be applied hot he should ascertain its temperature and see that specification requirements in this connection are carried out. He may also be required to note air temperatures when application is made. Size or grading tests of broken-stone or gravel cover may usually be made with a ¼-inch and a ½-inch or 1-inch field screen, as may be desirable.

186. Measurements. (*a*) The basis of payment for bituminous surface treatment may be the number of square yards of surface actually treated or may include separate items for work and materials used. The finished depth of carpet is seldom specified. In addition to measurements of length and width, the Inspector should in all cases measure the quantities of bituminous material and cover actually used if for no other reason than to ascertain their rate of application, which is usually covered by the specifications. For surface treatment bituminous materials are purchased by the gallon (§ 107) and may be measured in original tank containers (§ 365) or distributors. If measured in barrels it will be advisable to weigh the contents of a representative number of barrels and from the specific gravity of the material to ascertain its gallonage (§ 107*b*). If volume meas-

urement is made of a heated material, a correction for temperature will be necessary (§ 108). Volume or weight measurements (§§ 35–37) of mineral cover in cars or wagons may also be necessary.

(*b*) As a guide for surface treatment, Fig. 21 may prove useful. This diagram shows the number of gallons of bituminous material required to treat each 100 linear feet of

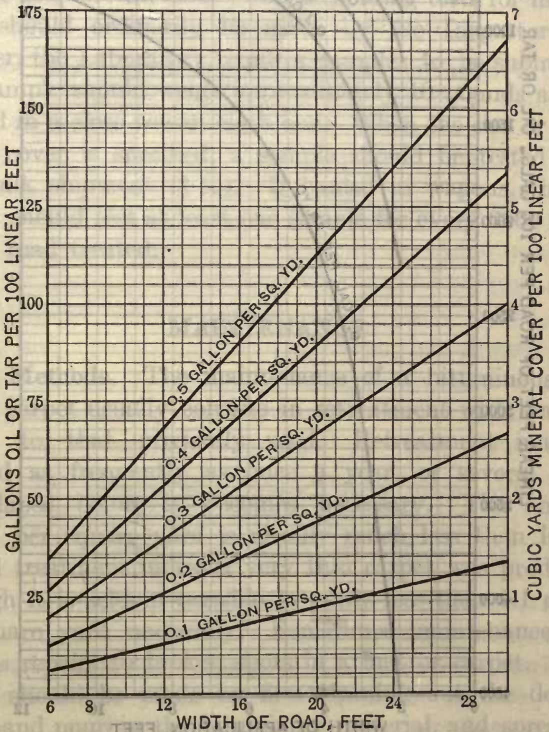

Fig. 21 Quantities of Materials Required for Bituminous Surface Treatments

road surface of various widths and at different rates of application. In case cover is used it also shows the probable number of cubic yards which will be required for 100 linear

feet of road according to the width of surface and the rate of application of bituminous material. Fig. 22 shows the

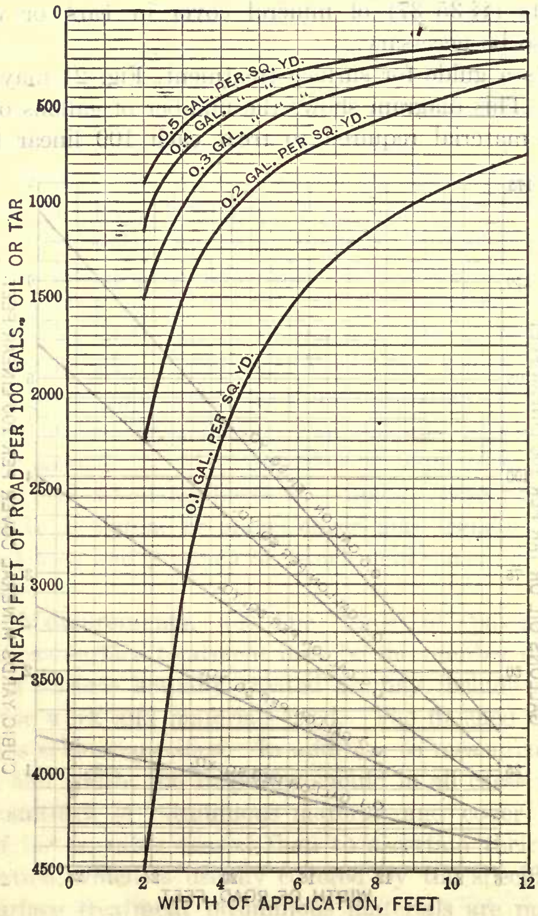

Fig. 22 Length of Road which may be Treated with 100 Gallons of Bituminous Material

length of surface which should be covered by each 100 gallons of bituminous material applied at various rates per

square yard for different widths of application. This diagram may be used in estimating the distance that a distributor of known capacity should travel before emptying itself.

187. Sampling. A sample of bituminous material (§§ 109–115) should be submitted to the laboratory, prior to its use, from each shipment received unless it has been sampled and tested prior to shipment. Such samples should be shipped in quart tin cans. Size or grading tests for mineral cover should ordinarily be made by the Inspector. If, however, the Laboratory requires samples to be submitted, each sample should weigh approximately 10 pounds and be shipped in a close-woven cloth bag. When the size or grading of cover is specified, a sample should be tested from each bulk shipment (§ 40). If hauled in wagons, the Inspector should test at least one sample for every 2000 linear feet of road treated.

MAINTENANCE

188. Methods. The maintenance of a bituminous surface or carpet usually consists in retreatment with material similar to that originally used. Retreatment may be required as frequently as once a year, or several years may elapse before it becomes necessary. The amount applied per square yard is usually much less than in the original treatment unless a very thin carpet was produced, although it is seldom possible to apply less than 0.1 gallon per square yard uniformly. Sometimes maintenance also involves repairs to broken spots in a mat or carpet. Such repairs should be made by first cleaning out the depressions, hand pouring the bituminous material, and spreading cover at the broken spots. Retreatments serve not only to build up a carpet which has worn away to a considerable extent, but also to rejuvenate it. For the latter purpose a cold application of relatively fluid bituminous material is advisable.

189. Inspection. Inspection of maintenance should be similar to that required for the original treatment. When it involves repairs to broken spots in an old carpet the greatest care should be exercised in preventing the use of an excessive amount of material at such spots, or soft fat places in the surface will be developed under traffic.

INSPECTOR'S EQUIPMENT

190. Treatment with Dust Preventives. The following equipment is all that will ordinarily be required:

For measurements:
- A 50-foot steel tape.
- A pocket rule (§ 387).

For sampling:
- A supply of 1-quart tin containers.
- A supply of gum labels for identification information.

For records and reports:
- A field diary and pencil.
- A supply of report forms (§ 404).
- A carbon paper for duplication of reports.

191. Treatment with Carpeting Mediums. In addition to that listed for treatment with dust preventives, the Inspector may require the following equipment:

For testing:
- A thermometer (§ 386).
- Two field screens (§ 371) as may be required by specifications. Openings of $\frac{1}{4}$ inch and $\frac{1}{2}$ or 1 inch are suggested.
- A spring balance with pan capacity of 10 pounds (§ 371).

CHAPTER X

INSPECTION OF BITUMINOUS MACADAM PAVEMENTS

GENERAL CHARACTERISTICS

192. Definition. "A bituminous macadam pavement [1] is one having a wearing course of macadam with the interstices filled by penetration methods with a bituminous binder." This definition represents present use of the term and classes the bituminous macadam apart from a wearing course constructed by mixing broken stone with bituminous material and from a macadam which has been surface treated with bituminous material. The kind of foundation upon which the bituminous macadam wearing course is laid has no connection with the use of this term.

193. Usual Method of Construction. There are a number of methods of constructing bituminous macadam pavements, but with occasional minor variations the method used in this country is as follows. Upon the foundation course is spread a layer of broken stone which is compacted, as in plain macadam construction, but without the use of water or screenings. Upon this layer of compacted stone hot bituminous material is then applied in such quantity as not merely to cover the surface but to flow into the voids between the stone fragments. The surface voids in the course are next filled by spreading and rolling in, a thin layer of stone chips. After removing all excess of loose chips a second application or seal coat of bituminous mate-

[1] Special Committee, Materials for Road Construction, Am. Soc. Civ. Eng.

rial is made, covered with stone chips, and the road completed by rolling.

DETAILS OF CONSTRUCTION

194. Foundations. (*a*) When constructing a bituminous macadam pavement from subgrade up, a broken stone foundation is commonly laid in exactly the same manner as for waterbound macadam (§§ 165*a*, 166*a*). When this is done it is preferable that the voids in the foundation should be filled with screenings so as to prevent the bituminous material from draining through and thus causing a deficiency of binder in the wearing course which is later constructed. Less frequently a Portland cement concrete foundation is constructed, but as heavy motor truck traffic increases the use of a concrete foundation for the heavily traveled bituminous macadam roads will probably become much more common.

(*b*) Quite often an old macadam, slag or gravel road is made to serve as foundation for the bituminous macadam pavement. If the old surface is in good shape it may be swept free of dirt and excess fine material and the bituminous macadam placed directly upon it. If badly out of shape it should first be repaired by patching (§ 173*b*) or resurfacing (§ 173*c*).

195. Spreading and Compacting Coarse Stone. When constructing bituminous macadam the coarse stone is spread exactly as for ordinary macadam (§ 165*a*) to produce a compacted depth of between 2 and 3 inches. Even greater caution should, however, be exercised to see that no segregation of sizes in the broken-stone product occurs during spreading. The stone should be rolled dry as in macadam construction (§ 166*b*) until the fragments have interlocked. Rolling should then cease. The extent of rolling is a most important matter. If the stone is not thoroughly interlocked before the bituminous material is applied, it is

difficult, if not impossible, to properly consolidate the road for heavy traffic, after application of the bituminous material. If, however, the stone is rolled beyond the point of interlocking, dust begins to accumulate on the surfaces of the fragments and tends to prevent proper adhesion of the bituminous material. There is also danger of filling the voids with fine material produced by crushing the larger fragments under the roller and thus preventing uniform penetration. In the case of relatively soft stone, over-rolling should be particularly guarded agianst, and in the case of relatively hard stone under-rolling should be especially avoided. If, after rolling, any surface irregularities appear they should be remedied by loosening the surface and removing or adding coarse stone as may be required. The main object is to secure a firm, even course of broken stone uniformly open or porous, so as to allow uniform penetration of the bituminous material which is next applied. After compaction no traffic should be allowed to pass over the coarse stone prior to application of the bituminous material.

196. First Application of Bituminous Material. (*a*) No bituminous material should be applied unless the entire depth of coarse stone is thoroughly dry and the air temperature in the shade is 50° F. or more. Before application is made any of the stone which has become mixed or coated with dirt should be removed and replaced with clean stone tamped or rolled into place. All ruts, bumps, or depressions should be remedied prior to application.

(*b*) The bituminous material, consisting of asphalt cement or refined tar, is applied hot either by means of hand pouring or with distributors. The proper temperature of application for asphalt cements usually lies between 275° F. and 350° F., while for tar products a range of 200° F. to 250° F. is proper. The material should be sufficiently fluid when applied to penetrate the course and not congeal as soon as it touches the road surface, but great care should be exercised that it is not overheated and thereby injured. It

is not advisable to exceed the maximum temperature limits above mentioned both from the standpoint of injury and proper distribution. One of the most important details to observe is that of uniform application at the proper rate. From $1\frac{1}{2}$ to $1\frac{3}{4}$ gallons per square yard is usually specified for a compacted $2\frac{1}{2}$-inch course of broken stone. On the basis of 30 per cent of voids about $4\frac{1}{4}$ gallons per square yard would be required to completely fill the course, but no attempt is made to do this, as such quantity would not only cause excessive bleeding in the finished road but would make it shifting and unstable under traffic. The main object is to coat the stone fragments so that surface contact will bond them together. If when applied the bituminous material is too fluid it is evident that the greater portion will find its way down to the bottom of the course, which is not desirable.

(*c*) When application is made by hand pouring, wide-mouthed pouring pots should be used which will distribute uniformly for a width of not less than 8 inches. A pot with a $\frac{1}{2}$-inch spout will also be found useful in touching up places where the surface may have been missed on first application. Pouring should begin at one edge of the road and proceed uniformly across its entire width. The spout of the pot should be held close to the road surface. An excellent method is to pour diagonally across the center line of the road so as to consume the contents of a pot at one trip across. The distance which should be covered in uniformly emptying a pot carrying a measured quantity of material, so as to secure the proper rate of application, should be carefully determined and constantly checked as the work proceeds. As an aid to uniform distribution alternating the direction of pouring of each succeeding pot is desirable.

(*d*) When application is made with a distributor the same general method is used and the same precautions observed as for surface treatments (§ 180*b*). Additional precaution should, however, be taken to avoid rutting the compacted

stone. A pressure distributor with very wide tires is desirable and should ordinarily be hauled by the roller during application. If a hose and nozzle distributor is used, the nozzle should be kept close to the road and pointing directly down. The use of a pouring pot will usually be found necessary in touching up places that may be missed by the distributor.

197. Filling Surface Voids. Immediately after the first application of bituminous material is made, and progressing with it, a thin uniform layer of small broken stone or stone chips should be spread over the surface in such quantity as to fill the surface voids and just cover the entire surface. The road is then rolled with the addition of more stone chips, if necessary, until the surface is thoroughly bonded. Brooming is sometimes required during rolling and, prior to the second application of bituminous material, should be used to clean the surface and remove all fine material which is not bonded to the road.

198. Seal Coat. (*a*) When the surface is thoroughly clean and dry the second application, or seal coat, of bituminous material is spread usually at the rate of from $\frac{1}{2}$ to $\frac{3}{4}$ gallon per square yard. The second application is made in exactly the same manner as described for the first, by means of either pouring pots or distributor. If the first application has been made by hand pouring diagonally across the road, the second application is made to cross the pouring lines of the first, and more than one trip is required to empty the pot.

(*b*) The second application should be immediately covered with stone chips as described for the construction of bituminous carpets (§ 181) and finished off by thorough rolling. The seal coat and cover is in effect a bituminous carpet which adds from $\frac{1}{4}$ to $\frac{3}{8}$ inch to the finished thickness of the pavement. The same type and grade of bituminous material is ordinarily used in both applications, but sometimes a first application of tar is followed with a seal coat of asphalt cement.

MATERIALS

199. Broken Stone. (*a*) Rock for bituminous macadam construction should possess the same characteristics as for ordinary macadam (§ 167), except that cementing value is an unimportant characteristic. The use of schist, shale, or slate should be excluded by specifications. The Inspector should, therefore, be able to identify them. A French coefficient of wear (§ 28) of 7 is usually considered the allowable minimum requirement, and sometimes a minimum toughness (§ 29) requirement is included in specifications.

(*b*) The size or grading of the coarse broken-stone product is in general the same as for macadam top course (§ 169*b*) but the small stone or chips differ from the screenings used for filling and bonding macadam in that they should be as free from dust as possible. Typical specifications of the U. S. Bureau of Public Roads contain the following requirements based upon actual screen tests which may be used in the laboratory or in the field (§ 371). The maximum size of coarse stone necessitates the construction of a course of not less than $2\frac{1}{2}$ inches compacted.

	Per cent
Coarse Stone	
Passing 2-inch screen, not less than . . .	95
Total passing $1\frac{1}{2}$-inch screen	25–75
Retained on 1-inch screen, not less than	85
Chips:	
Passing 1-inch screen, not less than . . .	95
Retained on $\frac{1}{4}$-inch screen, not less than	85

It is particularly important that the broken stone shall be free from dirt or dust occurring as a coating on the individual fragments.

200. Broken Slag. If slag (§ 168) is used the requirements for quality and size or grading are the same as for broken stone. In addition a minimum weight per cubic foot is also commonly specified, which property may have to

be determined by the Inspector (§ 375). A minimum weight of 70 pounds per cubic foot is sometimes specified, and a clause may be inserted in the specifications requiring a certain period of weathering before the slag is used.

201. Asphalt Cements. Asphalt cements (§ 96) manufactured to the desired range of consistency by refining petroleum or by fluxing refined native asphalts are commonly used in bituminous macadam construction. Fluxed native asphalts containing more than 6 or 7 per cent of non-bituminous material (§§ 96*c*, 133) are, however, seldom employed for this purpose. The most desirable consistency, expressed in terms of the penetration test (§ 125), will depend mainly upon climatic conditions to which the road is subjected, but may also be governed by the quality of stone used. Thus typical specifications of the U. S. Bureau of Public Roads require that the following ranges of penetration be met for climatic conditions generally prevailing in the United States.

	Penetration
Northern U. S.	120–150
Middle Belt U. S.	90–120
Southern U. S.	80–90

These requirements are, however, very general and may require modification in particular cases. Thus for the soft coralline rock of Florida, a residual petroleum similar to that used in the construction of bituminous carpets by hot application has been used with satisfactory results for the climatic and traffic conditions encountered. Under ordinary conditions, however, the use of asphalt of over 120 penetration creates a tendency to displacement of the pavement under heavy traffic, while a penetration of less than 80 tends to prevent uniform penetration into the course of broken stone. All asphalt cements should, of course, be free from water and should not foam when heated to the temperature specified for application (§ 196*b*). Those which have not been blown usually show a melting point by the ring-and-

ball method (§ 126) of between 35° and 60° C. Their maximum loss by volatilization at 163° C. (§ 129) is seldom over one per cent for oil asphalts and three per cent for Bermudez asphalt, which is the native asphalt most commonly employed. Penetration of the residue obtained from the volatilization test is frequently specified to be not less than one half of the original penetration. Other test requirements in specifications are usually included for the purpose of identification and control of uniformity (§ 411).

202. Refined Tars. Semisolid refined tars (§ 103) are manufactured to the desired range of consistency for bituminous macadam construction. They are much softer than the asphalt cements used for the same purpose, and their consistency is usually specified by the float test (§ 124). Climatic conditions to which the road is subjected form probably the most important consideration governing the proper float test limits that they should meet. Typical specifications of the U. S. Bureau of Public Roads require the following ranges of float test for general climatic variations in the United States:

	Seconds Float Test
Extreme Northern U. S.	90–120
Northern U. S.	120–150
Southern U. S.	150–180

These requirements are of course very general and may be modified to meet special conditions. However, a refined tar of less than 90 seconds float test is apt to drain to the bottom of the pavement and of more than 180 seconds float test to become very brittle in cold weather and to produce a slippery surface. The allowable maximum amount of free carbon (§ 102*c*) which the tar may contain is frequently set at 20 per cent. Refined water gas tars usually show less than 3 per cent. For bituminous macadam construction where the thickness of film of bituminous material on the surface of the stone fragments is considerably greater than

in bituminous concrete, free carbon up to 20 per cent may be ignored in connection with the rate of application required. No refined tar for this class of work should contain water nor foam when heated to the temperatures specified for application. Upon distillation (§ 132) the refined tar should yield not more than 1 per cent total distillate to 170° C., not more than 10 per cent to 270° C., and not more than 20 per cent to 300° C. The melting point by the ring-and-ball method (§ 126) of the residue from this test is sometimes specified to be not more than 65° C.

203. Field Tests. The Inspector is not usually required to make tests of any sort upon the bituminous materials used in bituminous macadam construction. He should, however, keep constant watch on the temperature to which the product is heated prior to application. His inspection of the quality and grading of broken stone or broken slag should be exactly the same as for ordinary macadam construction (§ 170). As a guide in ascertaining whether the finished road has been sufficiently compacted a short stout screw driver will be found useful. If properly compacted it should be difficult to force this instrument through the entire thickness of pavement. If it is easily forced in and may be worked about so as to loosen the surrounding stone, the pavement has not been thoroughly compacted.

204. Measurements. (*a*) Bituminous macadam pavements are usually measured and paid for on the basis of square yards of completed pavement in place, but sometimes include separate items for work and materials. The thickness of completed pavement is seldom accurately specified, although a requirement is frequently included specifying the loose or compacted thickness of coarse stone. In addition to the compacted thickness of coarse stone that of the seal coat or carpet should be considered in any measurement of finished thickness. This will usually amount to $\frac{3}{8}$ inch. In addition to measurements of length and width, measurements of loose or compacted thickness of coarse

stone should be made by the Inspector. As a check upon this and also in connection with the stone chips, measures of quantities by volume or weight (§§ 35–37) of stone or

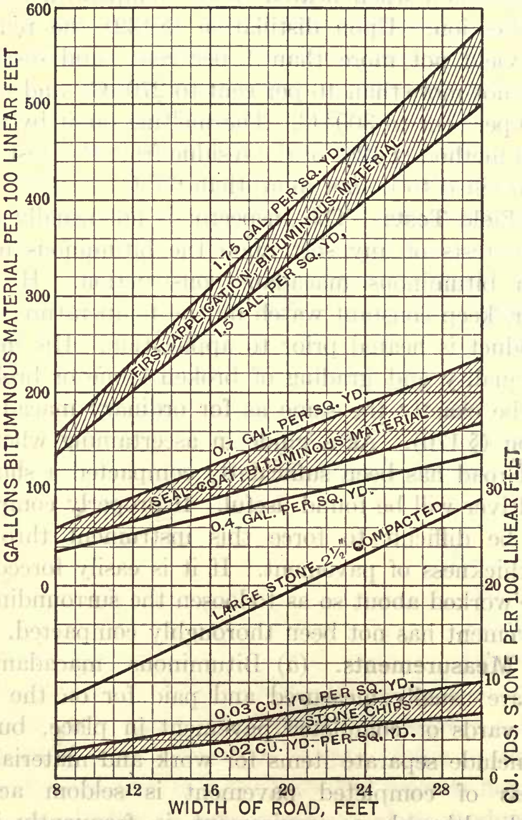

Fig. 23 Quantities of Materials Required for Bituminous Macadam Construction

slag in cars or wagons is advisable. The bituminous material is almost always purchased upon the gallon basis and may be measured in tank, barrel, or drum containers or in kettles or distributors. If measured in barrels or drums,

it will be advisable to weigh the contents of a representative number of packages, and from the specific gravity of the material to ascertain its gallonage (§ 107*b*). This will be necessary if purchase is made upon a weight basis. If volume measurement is made of heated materials, a correction for temperature will be necessary (§ 108).

(*b*) As a guide for bituminous macadam construction Fig. 23 may prove useful. This diagram shows the quantity of coarse stone and stone chips, loose measure, and bituminous material required to construct each 100 linear feet of pavement for various widths. The assumption of voids and compaction of coarse stone are as described for ordinary macadam (§ 171*b*).

The diagram illustrates a compacted depth of $2\frac{1}{2}$ inches of coarse stone, which is commonly specified. This means a loose depth of approximately 3 inches. A range of from $1\frac{1}{2}$ to $1\frac{3}{4}$ gallons of bituminous material for first application and from 0.4 to 0.7 gallon for seal coat is shown, together with the range in quantity of stone chips necessary to fill the surface voids and serve as cover for the seal coat. This diagram may be used in connection with the 45 per cent void curves in Figs. 4 and 5 in determining the number of tons of stone used or required, as explained under macadam (§ 171*b*). In the case of broken slag where the weight per cubic foot or cubic yard is usually ascertained, the diagram can be translated from volume to weight basis with little trouble.

205. Sampling. (*a*) Broken stone and broken slag for bituminous macadam construction should be sampled exactly as described for waterbound macadam (§ 172). Samples of coarse stone to be tested, usually by the Inspector, for size or grading should weigh between 30 and 40 pounds and samples of chips should weigh approximately 10 pounds. The Inspector should test at least one sample of each product from each bulk shipment (§ 40) or, if hauled in wagons, at least one sample for every 1000 linear feet of road, and whenever the grading of a product appears to vary markedly.

(*b*) A sample of bituminous material (§§ 109–115) should be submitted to the laboratory prior to its use from each shipment received unless it has been sampled and tested prior to shipment. Additional samples should be taken whenever there is any reason to suppose that the material has been injured by overheating. Samples should be shipped in quart tin cans with tight-fitting friction tops.

MAINTENANCE

206. Methods. (*a*) Ordinary maintenance of a bituminous macadam road involves surface treatment with bituminous material and cover, in which case both method and material may be as described in Chapter IX. Surface treatment is made not only to replace or build up the original seal coat worn away, but frequently to rejuvenate the bitumen near the surface if it has hardened materially through exposure. Cold surface treatments, as well as hot, are, therefore, often made, particularly in cases where a tar seal coat has been used. It is usually advisable in such cases to use the same type of material as was employed in original construction. In case an asphalt seal coat was originally applied, it would frequently seem advisable to use approximately the same penetration asphalt as was used in original construction. It is, however, difficult to clean the old surface so that the asphalt will adhere uniformly to it. A cut-back asphalt may, however, always be used advantageously.

(*b*) Holes, depressions, and ruts should be remedied by cutting them out so as to produce excavations with approximately vertical sides for the entire thickness of wearing course. The excavations may then be filled with coarse stone which is compacted and upon which is poured bituminous material at the same rate of application as in original construction. The patch may then be finished as in original work. When making such patches great care should be

taken not to use a surplus of bituminous material, which will almost invariably produce a fat spot and develop into a wave or bump. The most convenient method of patching is with a mixture of broken stone and emulsified asphalt or cut-back tar (§§ 333, 334).

(*c*) When the pavement is so badly broken up or out of shape as to need resurfacing it should either be removed or scarified and reshaped to form a foundation for a new pavement.

207. Inspection. Inspection of maintenance will usually be the same as for surface treatment (Chapter IX). For patching it will be similar to that required for original construction, in which case the extent of sampling and testing should depend upon the amount of work and materials involved.

INSPECTOR'S EQUIPMENT

208. Construction. The Inspector will find it advisable to be equipped with the following articles:

For Measurements:
- A 50-foot steel tape.
- A pocket rule (§ 387).

For Sampling:
- A supply of burlap bags for sampling stone for quality.
- A ball of stout twine.
- A supply of eyelet tags for identification information.
- A supply of 1-quart tin cans.
- A supply of gum labels.

For Testing:
- A hand sample of approved rock for visual comparison if broken stone is used. A small pocket magnifying glass may also prove useful.
- A set of field screens with suitable openings as may be covered in specifications for size (§ 371). Openings of 2″, $1\frac{1}{2}$″, 1″ and $\frac{1}{4}$″ are suggested.

A spring balance with pan capacity of 10 pounds (§ 371).
A cubic foot measure for determining weight per cubic foot in case broken slag is used (§ 375).
A stout screw driver about 6 inches long.
A thermometer (§ 386).

For Records and Reports:
A field diary and pencil.
A supply of report forms (§ 404).
A carbon paper for duplication of reports.

209. Maintenance. For maintenance the Inspector's equipment will ordinarily be the same as for surface treatment with carpeting mediums (§ 191). If extensive patching is involved, however, he may in addition require certain items covered under construction (§ 208).

CHAPTER XI

INSPECTION OF CONCRETE FOUNDATIONS AND PAVEMENTS

GENERAL CHARACTERISTICS

210. Composition. Without descriptive prefix the term "concrete" is generally understood in this country to mean a mixture of Portland cement (§ 65) with coarse and fine mineral aggregate and water. Coarse aggregate may consist of broken stone, broken slag, gravel or shell which will be retained on a $\frac{1}{4}$-inch screen. Fine aggregate may consist of sand, or screenings from any of the above-mentioned materials which will pass a $\frac{1}{4}$-inch screen. While Portland cement is almost invariably used as the bonding element for concrete road structures, natural cement (§ 72) or Puzzolan cement (§ 61) may be used to serve a similar purpose.

211. Proportioning. The strength and other resistant qualities of well-mixed and well-cured concrete depend not only upon the quality of the various constituents but upon the relative proportions in which they are present. In specifications these proportions are almost invariably stated upon a volume basis for cement, fine aggregate and coarse aggregate. Thus a 1:2:4 concrete is composed of one part by volume of cement, two parts by volume of fine aggregate, and four parts by volume of coarse aggregate. Various proportions are used in highway work, depending upon the conditions to which the concrete will be subjected, its thickness and the character of the fine and coarse aggregates. Within certain limits the strength of concrete depends upon the proportion of cement which it contains. As cement is,

however, by far the most expensive constituent, its proportion is kept as low as practicable, particularly in foundation work. A lean concrete is one containing a relatively small proportion of cement such as 1 part to 9 parts of fine and coarse aggregate combined, while a rich concrete is one containing a relatively large proportion of cement such as 1 part to 5 parts of total aggregate. The exact proportion of water to be used in mixing concrete cannot be specified to advantage, but this matter is controlled by describing the consistency which the wet mix should possess and after work has commenced measuring the amount which will produce the desired consistency and adhering to such proportion as long as uniformity in consistency is maintained thereby.

212. Properties. After setting, concrete is a monolithic mass possessing considerable compressive strength but not sufficient tensile strength to prevent the development of contraction cracks in cold weather when laid under ordinary conditions, as a large slab upon a natural soil subgrade. Its hardness, toughness, and resistance to abrasion are largely dependent upon the extent to which these properties are possessed by the coarse aggregate material which always predominates. The coarse aggregate, however, is bound together with mortar composed of fine aggregate and cement and the strength of the entire mass is greatly influenced by the character and grading of the aggregate and the proportion of cement which it carries.

213. Types of Construction. Considering the highway proper there are two general types of concrete construction, depending upon the immediate use to which the structure will be put. These are foundation and pavement proper. For both, the method of construction is quite similar. As, however, the concrete foundation is protected from many of the destructive agencies to which the pavement is subjected, the proportion and even the character of its constituents may be quite different. The concrete pavement,

like the foundation, is usually laid in a single course upon the prepared subgrade, but sometimes, to lower cost and utilize local material, which is not suitable for wearing surface, the pavement is laid in two courses. In such cases the lower course may be considered as foundation, although before it sets the upper course is laid upon it so as to produce a single monolithic structure throughout the entire depth. Foundations, as such, are seldom laid with expansion joints but quite frequently transverse expansion joints are constructed throughout the entire depth of concrete pavements at regular intervals. Such joints are usually filled with bituminous material or a prepared bituminous expansion joint (§§ 328–330). Occasionally the concrete pavement is reinforced with metal (§ 342) embedded in the concrete during construction. Frequently the design of concrete foundation or pavement includes an integral curb construction. In the case of foundation work this may also involve the construction of a concrete gutter simultaneously with that of the foundation and curb.

IMPORTANT DETAILS OF CONSTRUCTION

214. Preparation of Subgrade. Subgrade preparation for concrete foundations and pavements is quite similar to that described for macadam construction (§ 164). The subgrade is usually made flat or without crown. Sometimes, however, as in the case of alley construction, if the surface carries a dished or inverted crown, that of the subgrade is made to conform with it. With this exception, therefore, the thickness of a concrete foundation or pavement is not uniform throughout its width, but is greater at the center than at the sides.

215. Proportions. (*a*) The relative proportion (§ 211) of constituents to be used in the preparation of concrete may be specified upon a very definite volume basis such as 1:3:6 or $1:1\frac{1}{2}:3$. When mixing, however, it may be found desir-

able to slightly vary the relative amounts of fine and coarse aggregate so as to obtain a denser mix or one which can be worked more readily. It is, therefore, preferable that specifications state definitely the proportion of cement to total coarse and fine aggregate such as 1: 9 and to further require that it shall approximate a more definite composition such as 1: 3: 6. In addition specifications may definitely require a stated amount of cement to be used per cubic yard of concrete.

(*b*) Selection of the most economical and desirable proportions for any given work will depend upon a number of considerations. In general it is desired to obtain a concrete of maximum density. The percentage of voids in both coarse and fine aggregate is, therefore, an important factor. In order to fill voids under practical working conditions, however, it is necessary to use somewhat more than the theoretical amounts of void-filling material. For foundation construction proportions of cement to total aggregate usually lie between 1: 10½ and 1: 6. Common specific proportions are 1: 3: 6 and 1: 2½: 5. For concrete pavements, proportions of cement to total aggregate lie between 1: 6 and 1: 4. Best practice seems to call for specific proportions of 1: 2: 3 for broken-stone concrete and 1: 1½: 3 for gravel concrete. In two-course work, the proportions may differ for the individual courses. Thus, the Committee on Concrete Roads and Pavements of the American Concrete Institute has recommended for bottom course a 1: 2½: 4 mix and for top course a 1: 1½: 2½ mix.

(*c*) Products which consist of a combination of coarse and fine aggregates should not be used in concrete mixtures unless first screened and recombined in proper proportions. This is due to the fact that such products are seldom uniform, and unavoidable segregation of sizes will result during handling. In some specifications, however, as much as 15 per cent of fine aggregate passing the ¼-inch screen is allowed to be present in the coarse aggregate (§ 222,*b*,*c*)

and as much as 15 per cent of coarse aggregate retained on the $\frac{1}{4}$-inch screen is allowed to be present in the fine aggregate (§ 223*b*). This is only permissible when due allowance is made in setting the proportions actually measured, and when specifications are based upon a fixed proportion of cement to combined coarse and fine aggregate. It may be assumed that the presence of 15 per cent or less of fine aggregate in the coarse only exists as a void-filling medium and that a measured volume of the coarse aggregate would not be noticeably reduced by the removal of this fine. It may also be assumed that the removal of 15 per cent or less of coarse aggregate from the fine will not reduce its volume 15 per cent because the large particles exist as individuals suspended in the mass of fine aggregate. The removal of any number of particles, therefore, reduces the volume of fine aggregate only by the absolute volume of such particles and the percentage of voids in the remaining fine aggregate is greater than it was before. With these considerations in mind and working on a 45 per cent void basis for both coarse and fine screened aggregates, the following formulas may be used to ascertain the actual number of parts of coarse and fine aggregate which should be measured in order to conform with any specified proportions. In these formulas,

a = per cent of coarse aggregate passing the $\frac{1}{4}$-inch screen.
b = per cent of fine aggregate retained on the $\frac{1}{4}$-inch screen.
p = parts by volume of coarse aggregate required to 1 part of cement.
p' = parts by volume of fine aggregate required to 1 part of cement.
x = parts by volume of coarse aggregate to actually use.
y = parts by volume of fine aggregate to actually use.

$$x = \frac{5(2000p - 20bp' - 11bp)}{10000 - 55b - ab}$$

$$y = \frac{100(100p' - ap)}{10000 - 55b - ab}.$$

If in these formulas a and b are both zero, then $x = p$ and $y = p'$. To illustrate the use of these formulas, suppose a 1:2:4 mix is required from coarse aggregate containing 15 per cent fine particles, and fine aggregate containing 15 per cent coarse particles. Then

$$x = \frac{5[(2000 \times 4) - (20 \times 15 \times 2) - (11 \times 15 \times 4)]}{10000 - (55 \times 15) - (15 \times 15)}$$

$$= \frac{33700}{8950} = 3.77.$$

$$y = \frac{100[(100 \times 2) - (15 \times 4)]}{8950} = \frac{14000}{8950} = 1.56.$$

The actual proportions to measure would then be 1:1.6:3.8 instead of 1:2:4. While the proportion of cement to total fine and coarse aggregate is apparently greater than that required, it is not in reality, as may be demonstrated by separating both aggregates on the $\frac{1}{4}$-inch screen and measuring them separately.

216. Mixing. Concrete for foundation and pavement construction is almost invariably mixed by machines of which there are two general types, the batch mixer and the continuous mixer. The use of a batch mixer is commonly specified because control of uniformity of output is more assured. With a batch mixer of known capacity the proper amounts of coarse aggregate, fine aggregate and cement, to give the specified proportions, are measured and introduced into the mixing drum. A measured quantity of water is then added, after which mixing should be carried on, preferably for a full minute. This is an important matter which should be covered by specifications. Some mixers are equipped with timing devices to insure that each batch gets the proper amount of mixing, also with water measuring and discharging devices, the use of which is very desirable. After mixing a batch, the entire contents of the mixer should be discharged before attempting to mix a new batch.

217. Consistency. The consistency of fresh concrete, is controlled by the amount of water used and should be such as to flatten out and quake, when deposited, but not flow or segregate. The proper quantity of water should be determined by the Engineer and not varied without his consent. As a rule, in order to obtain maximum strength as little water should be used as possible to secure a product which may be properly placed and finished. Because of increased ease in working a strong tendency exists to use more water in the mix than is desirable.

218. Placing and Shaping. (*a*) The concrete should be placed between suitable side forms held rigidly in position. If inside stakes are used they should be removed as they are reached in placing the concrete. The forms should have the same height as the specified thickness of concrete at the sides and should be well greased or soaped prior to placing the concrete. At time of placing concrete the subgrade should be neither bone dry nor wet. If dry or dusty it should be lightly sprinkled with water. Concrete is sometimes deposited from the mixer by means of boom and bucket and sometimes by open chute. In either case care should be taken that segregation of the aggregate does not occur. If a chute is used its pitch should be sufficient to deliver concrete of the proper consistency. Concrete should be spread to the required depth by means of shovels and not with rakes, and it should be well spaded against forms. Strike boards and lutes may also be used to place concrete. Concrete should not be placed upon a frozen subgrade nor when the air temperature is below 35° F. unless adequate means are employed to heat the aggregate and mixing water. Concrete should be placed as soon after mixing as practicable and never later than 30 minutes thereafter. At the end of each working period a vertical bulkhead should be placed across, and at right angles to, the center line of the road, and the concrete worked up to and against it to produce the same cross sectional area as the rest of the work. Upon

removing the bulkhead, the joint should be wetted just prior to placing new concrete against it.

(*b*) If expansion or contraction joints are to be constructed at regular intervals, all work between joints should be continuous. Expansion joints should be constructed by means of a bulkhead of suitable thickness cut to the exact cross section of the pavement. Prepared fillers are lightly attached to the top of the bulkhead until the concrete is placed against both sides of it, after which the bulkhead is carefully removed leaving the filler in place and the concrete on both sides tamped and shaped against it. The filler should project above the finished surface and later may be cut down. For poured joints the bulkhead is allowed to remain until the concrete is sufficiently set to preserve its edge. It is then removed and the slot later filled by pouring in the heated bituminous filler. It is important that expansion joints extend to the extreme edges and that they contain a suitable filler for their entire length. If even a half inch or so is left solid at the end of the joint, or becomes filled with incompressible material, the corner of the slab may crack, or shear off, for some distance back, when the concrete expands. If joints are constructed to provide for contraction only, a thin sheet of metal, bituminous fabric or tar paper is used for breaking joints and the work may proceed continuously. All expansion joints should extend through the entire thickness of pavement. Contraction joints are sometimes made to extend from the bottom to within an inch or less of the finished surface, in which case they are called invisible joints.

(*c*) When wire mesh or expanded metal is used for reinforcement it is usually placed at least two inches below the surface and in lapped widths, as may be specified, parallel to or across the center line of the road. Circumferential reinforcing consists in placing steel bars around each slab near the edges. When placing concrete great care should be taken to work the concrete around

and in close contact with all surfaces of the reinforcing metal.

(*d*) When combination foundation or pavement with integral curb and gutter, or curb, is to be constructed, the integral construction should be placed immediately, and never later than thirty minutes, after the foundation or pavement is placed. Such construction should be thoroughly tamped and spaded against the forms which have been placed for it.

219. Finishing the Surface. (*a*) The surface of concrete foundations is usually finished with a template, cut to the desired crown, and worked from the side forms. The surface should be thoroughly compacted and brought to true shape immediately after placing. A perfectly smooth surface is desirable for the later construction of a brick or block pavement. For bituminous pavements it should be slightly rough, with the coarse aggregate thoroughly embedded but not covered with a coating of mortar. The finished surface should be free from all depressions or other irregularities.

(*b*) There are various methods of finishing the surface of concrete pavements. A heavy steel template is commonly used on pavements which are not too wide for compacting and shaping by this method. For very wide pavements lutes may be used for shaping, provided metal stakes are set at intervals across the road to serve as guides, and pulled out as soon as the concrete is worked around them to the proper height. In either case unless a finishing machine is used the concrete should next be rolled by hand with a long-handled metal roller. This roller should be operated from the sides of the road so as to pass across it from one edge to the other, advancing in a slightly diagonal direction. The concrete should be rolled until free water ceases to come to the surface. A final finish is then given with a strip of canvas or rubber belting from 6 inches to 1 foot in width and about 2 feet longer than the width of

the road. The belt should be worked with a longitudinal and crosswise motion in the same manner as a template. A second finishing with the belt should be given when the excess surface water has disappeared. All concrete adjacent to transverse expansion joints should be finished with a split wood float operated from a bridge which should not touch the concrete at any point. Edges of joints are rounded with an edging tool to a radius of approximately $\frac{3}{16}$ inch and the edges next to the side forms are rounded to a radius of approximately 1 inch.

220. Curing. As soon as the concrete has received its final finish, it should be protected with a canvas cover suspended above its surface. When it has hardened sufficiently the canvas protection is replaced by a covering of earth one inch or more in thickness. The earth covering should be sprinkled from time to time to keep it moist so that hardening of the concrete will proceed slowly. After a period of not less than 10 days, the covering is removed but the pavement kept closed to traffic for an additional period of from 4 to 10 days, or longer if the air temperature is below 50° F. Sometimes instead of using an earth covering, the surface of the concrete is flooded with about 2 inches of water which is held by earth dams built at the sides and at intervals across the road after the pavement has sufficiently hardened under the canvas protection.

MATERIALS

221. Cement. The physical and chemical characteristics of Portland cement have been so well standardized (§ 64) that specifications for its use in highway work usually require only that "it shall conform to the standard specifications of the American Society for Testing Materials," which have already been stated.

222. Coarse Aggregate. (*a*) For highway construction broken stone or gravel is most commonly used as coarse

aggregate, although broken slag has also been used to some extent. As it is most important that the properties of coarse and fine aggregates should be carefully controlled, specifications usually allow for the presence of little or no fine material passing the $\frac{1}{4}$-inch screen. Unscreened, crusher or shovel run products or unscreened gravel should never be used for coarse aggregate. The material of which the coarse aggregate consists should be sound and free from dirt or coating of any sort. Particular attention should be paid to preventing its admixture with dirt when stored in piles along the road. The absence of soft, thin, elongated or laminated fragments should be specified.

(*b*) Laboratory test requirements for quality of rock or gravel used as coarse aggregate in concrete foundations are seldom included in specifications. In the case of slag, however, a minimum weight per cubic foot for the commercial product may be specified, and 60 pounds is not considered an unreasonable minimum limit. A certain period of weathering before the slag is used is also sometimes required. Size or grading requirements should preferably be specified upon the basis of laboratory screen tests. As an illustration the following requirements are cited from typical specifications of the U. S. Bureau of Public Roads in connection with broken stone or gravel coarse aggregate.

	Per cent
Passing 3-inch screen, not less than.......	95
Total passing $1\frac{1}{2}$-inch screen.............	40–75
Retained on $\frac{1}{4}$-inch screen, not less than...	85

The 15 per cent of coarse aggregate which is allowed to pass the $\frac{1}{4}$-inch screen is, however, only permissible when specifications are based upon a fixed proportion of cement to combined coarse and fine aggregate and allowance is made for slight variations in the relative amounts of coarse and fine aggregates (§ 215*c*).

(*c*) For the construction of a concrete pavement or wear-

ing course, quality requirements based upon laboratory tests should preferably be given in specifications. Only tough and fairly hard material should be allowed. While gravel has been used to a considerable extent it is not in general considered as satisfactory as broken stone, as its uniformity of quality is more difficult to control. This fact is also true of broken slag. The U. S. Bureau of Public Roads' typical specifications for broken stone to be used as coarse aggregate in concrete pavements requires a French coefficient of wear (§ 28) of not less than 8 and a toughness (§ 29) of not less than 8. The size or grading of aggregate is specified as follows:

	Per cent
Passing 2-inch screen, not less than........	95
Total passing 1-inch screen................	40–75
Retained on $\frac{1}{4}$-inch screen, not less than....	85

As in the case of foundation material specifications, the 15 per cent allowed to pass the $\frac{1}{4}$-inch screen is only permissible when specifications are based upon a fixed proportion of cement to combined coarse and fine aggregates and allowance is made for slight variations in the relative amounts of coarse and fine aggregates. If specifications allow for the use of gravel the soundness of individual pebbles (§ 374) should be carefully covered. If slag is allowed a minimum weight per cubic foot should be specified in connection with a minimum French coefficient of wear the same as for rock. A minimum weight per cubic foot of 70 pounds is sometimes set. A clause may also be inserted requiring a certain period of weathering before the slag is used.

223. Fine Aggregate. (*a*) The use of sand is most commonly specified as fine aggregate for concrete, but sometimes stone screenings or a mixture of sand and stone screenings is permitted. In any case the fine aggregate should consist of clean, hard, durable uncoated particles free from clay, loam, mica and organic matter. All of the material is usually specified to pass a $\frac{1}{4}$-inch screen and an

excess of silt or dust is eliminated by a maximum allowance for material which will pass a 100-mesh sieve. In addition to grading requirements, specifications frequently include a minimum mortar strength test requirement (§ 58). Sometimes the use of a product which will not pass the mortar strength test is allowed, provided an additional amount of cement is used in the concrete equivalent to the additional quantity required to bring the mortar strength up to that specified.

(*b*) As an illustration of specification requirements for grading and strength of sand for concrete foundations, the following is taken from typical specifications of the U. S. Bureau of Public Roads:

	Per cent
Passing $\frac{1}{4}$-inch screen	100
Total passing 20-mesh sieve, not less than	20
" " 50 " " " more than	50
Passing 100-mesh sieve, not more than	10
Removed by elutriation (§ 53), not more than	5
Mortar strength of 1:3 briquettes, not less than 75 per cent of standard 1:3 briquettes made with the same cement.	

If stone screenings or a combination of screenings and sand are allowed to be used, 100 per cent should be required to pass a $\frac{1}{2}$-inch screen and at least 85 per cent to pass a $\frac{1}{4}$-inch screen. The 15 per cent allowed to be retained on the $\frac{1}{4}$-inch screen is only permissible under the conditions mentioned for coarse aggregate gradings in connection with material passing this screen (§ 222*b*). That portion of the stone screenings which passes the $\frac{1}{4}$-inch screen should then be subjected to the same grading and strength requirements as given for sand. Sometimes these requirements are made as rigid as for sand to be used in pavement or wearing course construction.

(*c*) Grading and strength requirements for sand for concrete pavement or wearing course are covered as

follows by typical specifiactions of the U. S. Bureau of Public Roads:

	Per cent
Passing $\frac{1}{4}$-inch screen	100
Total passing 20-mesh sieve	50–80
Total passing 50-mesh sieve, not more than	20
Passing 100-mesh sieve, not more than	5
Removed by elutriation (§ 53), not more than	3
Mortar strength of 1:3 briquettes, not less than 100 per cent of standard 1:3 briquettes made with the same cement.	

224. Water. All water used in mixing concrete should be reasonably clear, free from harmful amounts of oil, acid, alkali or vegetable substance and neither brackish nor salty.

225. Reinforcing Metal. When construction involves the use of wire mesh or expanded metal reinforcement a minimum weight of 25 pounds per 100 square feet is usually specified. The ratio of effective areas of the reinforcing members at right angles to each is also sometimes specified. If steel bars are used, their size and shape are specified together with quality requirements which can only be determined by laboratory test, although a cold bend test (§ 342*b*) may sometimes be made in the field.

226. Hydrated Lime. When the use of hydrated lime is specified in concrete construction, the lime is ordinarily required to meet the specifications adopted by the American Society for Testing Materials (Standard C6–25). These specifications cover chemical properties as determined by laboratory test, also a laboratory test for constancy of volume. In addition it is required that not more than $\frac{1}{2}$ per cent shall be retained on a 30-mesh sieve. Hydrated lime is incorporated in the concrete on the basis of a specified percentage of the weight of cement used. Thus if 10 per cent of the weight of cement is specified 9.4 pounds will be required for each bag of cement used.

227. Materials for Expansion Joints. Bituminous fillers (§§ 97, 104) are usually specified for filling expansion joints. The application and properties of such fillers are described later (§§ 328–330).

228. Field Tests. (*a*) Cement, joint-filling materials, metal reinforcing, and hydrated lime if it is used, are usually subjected to laboratory tests only. Water for mixing is seldom tested unless reason exists for believing it to be unsuited for use, in which case the sample is submitted to the laboratory for examination. Both coarse and fine aggregates should, however, be subjected to field tests by the Inspector in order to insure proper control of the mix. In addition, if expansion joints are to be filled with heated bituminous material the Inspector should observe the temperature to which it is raised.

(*b*) Broken stone for coarse aggregate is usually approved upon laboratory tests for quality made in advance of the work, in which case the Inspector will find it convenient to secure a small specimen from the sample tested for the purpose of visual comparison with the product furnished on the job. If gravel is used it should be examined for quality as described under Gravel Roads (§ 151*b*) and particular attention paid to the possible presence of a clay coating on the individual pebbles. In the case of slag, determinations of weight per cubic foot should be made from time to time. All products should be constantly watched to see that they do not contain an excess of thin or elongated pieces, disintegrated fragments, dirt or other objectionable material. The size or grading of coarse aggregate should be frequently determined for conformity with specification requirements and a set of selected field screens (§ 371) from the maximum diameter to $\frac{1}{4}$ inch should be used for this purpose.

(*c*) Fine aggregate should be subjected to visual inspection for the purpose of detecting clay or organic coatings on the individual particles. If the presence of organic

matter is suspected the aggregate may be subjected to a rough field test (§ 372) to determine whether there is sufficient present to make the use of the product inadvisable. Field tests for the determination of silt (§ 373) may also be occasionally required. In addition, the size or grading of fine aggregate should be determined at frequent intervals for conformity with specification requirements. A set of selected field sieves (§ 371) in addition to the $\frac{1}{4}$-inch screen should be used for this purpose.

229. Measurements. (*a*) As the proportioning of concrete is almost invariably specified upon a volume basis, it is necessary for the Inspector to keep constant watch upon the relative volumes of the constituents used for each batch in order to assure a uniform product. Cement is commonly used by the sack of 94 pounds, which is specified as one cubic foot. Coarse and fine aggregates are measured separately, usually in wheelbarrows of 2 or 3 cubic feet capacity. The contractor should furnish a 1-cubic-foot measuring box which should be used in connection with each product for gauging and marking the capacity of wheelbarrows. When the proportions or size of the batch are such as to require fractional capacity loads, such amounts should be gauged and shown by a line painted at proper height around the inside of the barrow. In measuring whole or fractional barrow loads the material should be struck level and level loads only should be delivered to the mixer. In addition to capacity measurements the Inspector should see that the proper number of loads and fractions of loads of each aggregate are delivered to the mixer for each batch. The same is true in connection with the number of bags of cement.

(*b*) Concrete foundations and pavements are commonly paid for upon a square yard basis, complete in place, and sometimes by the number of cubic yards as determined by end area section and length. Extra thickness at weak spots in the subgrade when called for are paid upon the number

of cubic yards actually placed. When integral curbs and gutters are constructed and a square yard basis is used, their surface areas are included, but no allowance is made for extra thickness, as the bid price is supposed to include this item. The same is true of reinforcement and expansion

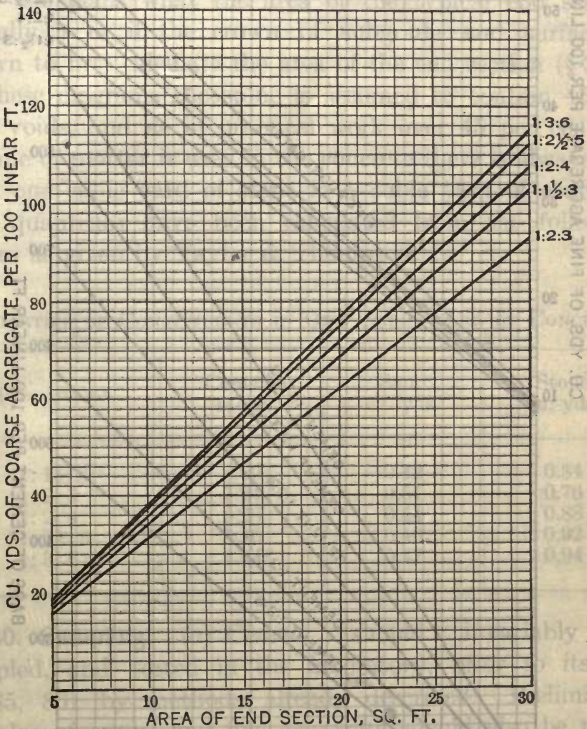

Fig. 24 Coarse Aggregate Required for Concrete Construction

joint materials. The Inspector should, of course, make measurements of length, width and depth of concrete but in addition should keep track of the actual and relative volumes of the constituents of the mix, both as a check on linear measurements and upon proportions used. For this purpose Figs. 24 and 25 will prove useful. In concrete foun-

dations and pavements the thickness of concrete throughout the width of the structure is seldom uniform, nor have

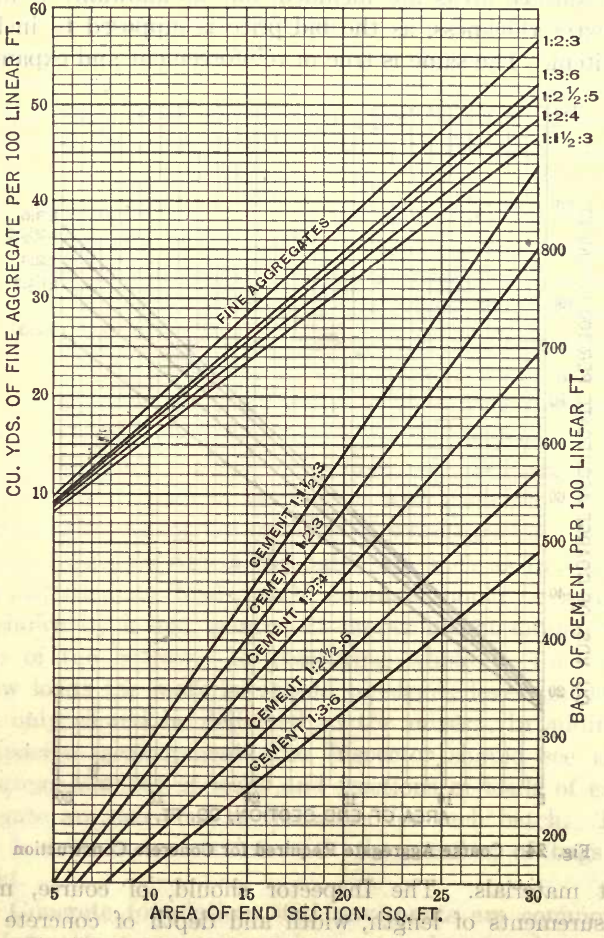

Fig. 25 Fine Aggregate and Cement Required for Concrete Construction

any general standards been adopted relative to thickness or crowns for different widths. The diagrams, therefore, show

the number of cubic yards of coarse aggregate and fine aggregate and the number of bags of cement for each 100 linear feet of structure for various end section areas in the case of five common proportions. To use these diagrams in connection with field work it will be necessary to ascertain from the plans what the area of the typical end section actually is or if the crown of subgrade and surface is known to first calculate the area of the end section (§ 360). In these diagrams the stone is assumed to contain 45 per cent voids, and as in practical work over 45 per cent by volume of mortar is used in the concrete there is always less than one cubic yard of stone in a cubic yard of concrete. The quantities have been calculated from the following values as given by Taylor & Thompson.[1]

QUANTITIES OF CONSTITUENTS IN ONE CUBIC YARD OF CONCRETE

Proportions	Cement sacks	Sand cu. yds.	Stone cu. yds.
$1:1\frac{1}{2}:3$	8.00	0.42	0.84
1:2:3	7.24	0.51	0.76
1:2:4	6.28	0.44	0.88
$1:2\frac{1}{2}:5$	5.20	0.46	0.92
1:3:6	4.44	0.47	0.94

230. Sampling. (*a*) Cement should invariably be sampled, and tested in the laboratory, prior to its use (§§ 85, 86) by methods already described. Preliminary samples of coarse and fine aggregate should also be taken and submitted to the laboratory, particularly in connection with quality and mortar strength tests. (For sampling broken stone and broken slag see §§ 38 to 40 and 172; for gravel see §§ 59, 60 and 153; and for sand or other fine aggregate see §§ 59 and 60.) Size or grading tests of both coarse and fine aggregates should be made throughout

[1] Concrete Plain and Reinforced, John Wiley & Sons. Inc.

the work (§ 371) and also determinations of weight per cubic foot (§ 375), if required. Cement samples should weigh about 10 pounds each and be shipped in air-tight containers. Both coarse and fine aggregate samples should be shipped in close-woven cloth bags or tight boxes. The weight of coarse aggregate samples should depend upon the maximum size of particles present (§ 153*a*). Fine aggregate samples should ordinarily weigh 10 pounds.

(*b*) During use at least one sample of coarse and fine aggregate should be tested by the Inspector from each bulk shipment (§§ 40, 60*c*). In addition one sample of both should be tested for every 1000 square yards of foundation work and for every 500 square yards of pavement. If slag is used, weight per cubic foot determinations, if required, should be made when sampling for size or grading.

(*c*) A sample of each shipment of expansion joint material (§§ 329, 330), metal reinforcing (§ 342) and hydrated lime (§ 226) should be submitted to the laboratory unless sampled and tested prior to shipment. In addition samples of the concrete actually used are sometimes required for laboratory strength tests. When this is so, suitable forms or molds, of stiff pasteboard or steel, are furnished the Inspector. Thus, the New York State Highway Commission requires that two specimens be prepared for each 500 cubic yards of concrete. Samples used in preparing these specimens are taken at random from the batches used and are molded at the time and place of mixing. The samples are allowed to remain in the molds for two days and are then aged for 19 days under the same conditions as the concrete structure. On the 21st day they are shipped to the laboratory in a box properly protected from breakage. Such specimens should be marked for identification and should be accompanied by information giving the location on the work from which they were taken, proportions of the mix, method of curing, etc.

MAINTENANCE OF CONCRETE PAVEMENTS

231. Methods. (*a*) The earliest disintegration of properly designed and well-constructed concrete pavements is usually in connection with the formation of cracks and spalling at both cracks and joints. Maintenance then consists in filling such places with hot bituminous material and covering with coarse dry sand. Prior to filling, cracks should be cleaned as thoroughly as possible. For cleaning fine cracks, the Committee on Roads and pavements of the American Concrete Institute recommend the use of an automobile tire pump. In the case of joints, the old joint material is sometimes removed for a depth of $\frac{1}{4}$ to $\frac{1}{2}$ inch before the new bituminous material is poured. When pouring the bituminous material, care should be taken to prevent its overflow for a width of more than one or two inches and a narrow spout pouring pot should be used for this purpose.

(*b*) Slight depressions are remedied by thorough cleaning followed by the application of bituminous material such as used in surface treatments (§ 183) and a covering of sand, care being taken to use no more material than is required to bring the patch flush with the surrounding surface. Pockets and deeper depressions are remedied by thorough cleaning and painting with bituminous material and filling with a cold mix bituminous aggregate (§§ 333, 334) the particles of which are usually between $\frac{1}{4}$ and $\frac{1}{2}$ inch in diameter. Such mixtures should be tamped into place and covered with coarse sand. Sometimes the repair is made by first filling the clean hole with the aggregate and pouring on the bituminous material.

(*c*) In the case of replacements, due to holes cut through the entire thickness of the concrete slab, the subgrade should consist of sound material thoroughly rammed into place. Any accumulation of water should first be removed. The sides of the cut should be cleaned and painted with a mix-

ture of neat cement and water just prior to filling with concrete. The concrete for small repairs is usually mixed by hand to a somewhat stiffer consistency than that used in original construction. It should be well tamped into place until the tamping brings free water to the surface. The patched area should then be struck true to the surrounding surface. The new concrete should be kept moist for four or five days and protected from traffic for at least 10 days.

(*d*) Concrete pavements are sometimes protected by surface treatment with bituminous materials (§ 183). When a concrete pavement becomes so worn as to require resurfacing it is usually made to serve as foundation for some other type of pavement. If, however, it is to be resurfaced with concrete the old pavement should first be thoroughly cleaned and brushed with wet grout just ahead of placing the new wearing course which should be laid as described under original construction. In such case joints in the new course should be placed directly over those in the old pavement. The Committee on Concrete Roads and Pavements of the American Concrete Institute has recommended that the resurfacing course should be not less than 3 inches thick and should carry reinforcement in the middle of the layer.

232. Inspection. Inspection of maintenance will usually be the same as for surface treatment (§§ 179–187) or patching bituminous roads (§ 207). In cases involving replacement or resurfacing with concrete, it should be the same as for original construction, in which case the extent of sampling and testing should depend upon the amount of work and materials involved.

INSPECTOR'S EQUIPMENT

233. Construction. The Inspector should ordinarily be equipped with the following articles:

For Measurements:

A 50-foot steel tape.

A pocket rule (§ 387).

A 1-cubic-foot box (should ordinarily be furnished by the contractor, together with paint and brush for gauging wheelbarrows).

For Sampling:

A supply of close-woven bags of suitable size for coarse and fine aggregates.

A ball of stout twine.

A supply of eyelet tags for identification information.

A few 1-quart tin cans with tight-fitting covers.

A supply of gum labels.

A supply of concrete molds if samples of cement are required.

For Testing:

A hand sample of approved rock for visual comparison, if broken stone is used.

A set of field screens and sieves with suitable openings as may be covered in specifications for size and grading. Screen openings of 3″, 1½″ and ¼″ are suggested for coarse aggregates for foundations. Openings of 2″, 1″ and ¼″ are suggested for coarse aggregates for pavements. For fine aggregates 20-, 50- and 100-mesh sieves are suggested (§ 371).

A spring balance with pan capacity of 10 pounds (§ 371).

A spring balance with pan capacity of 200 grams (§ 371).

A 100-c.c. glass cylinder for volumetric silt testing (§ 373) may be found useful.

A 3 per cent solution of sodium hydroxide and a 12-ounce graduated prescription bottle may be found useful for detecting organic impurities (§ 372).

A small pocket magnifying glass may also prove useful.

A thermometer, if heated bituminous material is to be used in expansion joints (§ 386).

For Records and Reports:

A field diary and pencil.

A supply of report forms (§ 404).

A carbon paper for duplication of reports.

234. Maintenance. For maintenance with bituminous materials the Inspector's equipment will ordinarily be the same as for surface treatment (§ 191). For extensive replacements or resurfacing with concrete it should be the same as for original construction (§ 233).

CHAPTER XII

BITUMINOUS PAVING PLANT INSPECTION

PAVING PLANTS

235. Function of Paving Plants. The function of a paving plant is to manufacture, from mineral aggregate and bituminous material, a hot paving mixture or composition which will be delivered upon the road as a finished product, under such conditions that it may immediately be spread to the desired thickness and compacted by rolling. Paving plant operations may, in a sense, be considered independent of the actual pavement construction, but there are several important factors that make it necessary for plant work and construction work to proceed simultaneously and to regulate one another to a considerable extent. It is, therefore, desirable that the paving plant be located as near as possible to the site of construction. A bituminous mixture unless first molded into blocks (§ 315) must be delivered to the road at such temperature that it may be readily spread. As such mixtures set up upon cooling, this means that the plant should produce and deliver material no faster than, and only at such times as, it can be immediately laid. On the other hand, the plant's output capacity is known and, as construction work is planned accordingly, the plant cannot at will work intermittently when called upon to supply mix without seriously interfering with the construction work and causing unnecessary expense. Moreover, the behavior of the bituminous mixture, when being spread or compacted, may indicate the desirability of slight modifica-

tions in the proportioning of constituents which are usually allowable under specification requirements. The closest coöperation should therefore exist between plant and pavement work and the inspection of both.

236. Duties of Plant Inspector. The plant inspector should have had sufficient experience to suggest modifications of proportions within specification requirements, which from time to time it may be desirable to make in order to produce a suitable and uniform product. He should carefully observe all details of plant operation, particularly in connection with the heating of the individual constituents, their measurement or proportioning, the period of mixing and the condition of the mix upon leaving the plant. He should keep a record of the temperatures to which both the bituminous material and the mineral aggregates are heated prior to mixing and the temperature of the finished mixture when discharged. He should test and record the consistency (§§ 378, 379) of the bituminous material used, particularly if fluxing is carried on at the plant, in which case he should see that the proper proportions of asphalt and flux are used and that a uniform product is obtained. He should make grading tests (§ 371) of the mineral aggregate constituents and see that at all times proper proportions of bitumen and aggregate are being used. He should see that weight or volume measurements are checked from time to time. In addition he should test (§ 380) certain types of mix to ascertain if the proportions are such as to produce a satisfactory product when laid and compacted. He should, as required, forward to the laboratory samples of the various constituents and of the mix itself for check and control tests. He may also at times be required to prospect for available sources of supply in connection with sand which may be used in the aggregate.

237. Types of Plants. (*a*) Bituminous paving plants as here considered are complete installations for heating, measuring or weighing, and combining all of the constitu-

ents of a bituminous mix. Hand mixing and the use of concrete mixers, with or without heating devices, in the preparation of certain classes of bituminous concrete are considered elsewhere (§§ 333, 334). There are three types of plants, all of which, however, operate along the same general lines. These are the permanent or stationary, the semi-portable and the portable plant. The permanent plant is mainly used in connection with the construction and maintenance of city pavements and is frequently owned and operated by the municipality. As it is only to be used in supplying material for a restricted locality, and portability is not a necessary feature, the settings are usually stationary and its design may involve heavier and more substantial equipment than for the other two types. The portable is of lighter construction and frequently of smaller capacity. It is constructed in two, and sometimes in three, units to facilitate moving it from place to place. Such plants are commonly used by contractors for relatively small isolated jobs where the plant may be operated at, or adjacent to, the site of work, and frequently moved along with the work. Semi-portable plants are of heavier construction but may be moved from place to place by rail. They are sometimes called railroad plants and are most conveniently set up and operated near a railroad siding. They are largely used by contractors for municipal work and in other localities where the yardage of construction warrants and rail facilities are sufficiently close to the work. Such plants are often given a more or less permanent position and set up in connection with municipal work.

(*b*) Some paving plants are designed to turn out only a single type of product, in which case certain parts of a general paving plant may be eliminated. Considering all types of bituminous mixtures used in highway construction with the exception of asphalt block (§ 315), the following machinery and equipment may be present in addition to the power and heating plant. An elevator, usually of the belt-

and-bucket type, is employed to carry the mineral aggregate to a drier or heating drum, but where the aggregate is to be heated as a batch, the measured material for each batch may be elevated directly to a storage bin, which discharges into the drier. In the first case a more or less continuous stream of heated aggregate is discharged into an elevator which lifts it to a hot storage bin, while in the second it is discharged directly into the mixer. The hot storage bin is sometimes divided into compartments and a rotary screen introduced between the drier and bin in order to separate the hot aggregate into two or more sizes. From the hot storage bin the aggregate is discharged into a measuring box from which it is emptied into the mixer. In any event, after the aggregate has entered the mixer a measured or weighed amount of heated bituminous cement is also introduced, and when the mixing is completed the finished product is discharged directly into wagons or wheel barrows. If a mineral filler is to be incorporated in the mix it is measured cold either in buckets or by a box device similar to that used for the main aggregate. The bituminous material equipment may include a hoist for lifting the material to the melting tank, or tanks, where it is rendered fluid by the application of heat. If it is not to be fluxed it is drawn or lifted by a special device directly from the melting tank to a measuring or weighing bucket which empties into the mixer. If fluxing is involved, a tank for holding flux oil should be supplied, together with means for measuring the amount drawn into the melting kettle in which the fluxing is then conducted. From the melting tank the fluxed material is led into a draw-off tank of equal capacity and afterwards lifted to the weighing bucket.

PLANT OPERATION

238. Storage of Materials. As received at the plant, mineral aggregate for bituminous mixtures is stored in piles, as near as possible to the elevator which is to convey it to

the drier or heater. It is frequently necessary to combine two or more sizes or grades of aggregate, in which case the different sizes or grades should be kept in separate piles. All aggregate should be stored so that it will not become mixed with dirt or other foreign material. Storage bins, in the plant proper, are of relatively small capacity and are intended for use only during its operation. Bituminous cements and fluxes are usually stored in barrels or drums (§ 92) except in the case of the more permanent set-ups where material may be purchased by the tank car and transferred to large storage tanks until used.

239. Heating Mineral Aggregates. The mineral aggregate is ordinarily dried and heated by passing it through a revolving metal drum which is heated from the outside and through which a constant stream of hot air or hot exhaust gases are forced. As it passes through the drum the aggregate is thrown about by means of baffle plates, or other device, so that it is not only heated by contact with the hot metal but also dried by intimate contact with the current of hot air or gases. A pyrometer is sometimes placed at the exhaust end to register the temperature of the aggregate as it passes the drum. The exhaust gases frequently remove considerable dust from the aggregate and are, therefore, sometimes passed through a dust collector. For this reason mineral filler when used is not ordinarily preheated. When two or more grades or sizes of aggregate are to be combined, they are usually fed simultaneously to the mixer in the proper volumetric proportions, being measured by shovels or wheelbarrows. If, however, the hot aggregate is to be separated before passing to the hot storage bin, no attempt need be made to proportion the sizes before they enter the drier other than to regulate their feed so that the storage bin will always contain a sufficient quantity of each size to produce a batch.

240. Separating the Aggregate. Segregation of sizes is very apt to occur during passage through the drier. This

is particularly true in the case of mixtures of coarse and fine aggregate such as a mixture of broken stone, with fragments over ½ inch in diameter, and sand. In such cases, therefore, it is advisable to pass the output of the drier through a rotary screen so as to separate it into suitable sizes which are held in separate compartments of the hot storage bin. In some plants this procedure is unnecessary if each mixing batch of aggregate is heated and dried separately. Even in the case of sand mixtures, however, a screen is often used to throw out all particles above a certain diameter.

241. Heating and Fluxing Bituminous Materials. Melting and fluxing tanks are heated either by direct fire or by means of steam coils, preferably the latter. For general use they should be provided with an agitating device to prevent settlement of any nonbituminous constituent which may be present in the bituminous material and to assist in fluxing. Agitation is secured either by a mechanical device or by means of steam or air jets forced up through the heated material from coils placed in the bottom of the tank. The fluxing process usually consists of combining refined asphalt (§ 96) with a petroleum residuum or flux (§ 95) in such proportions as to produce an asphalt cement of the desired consistency or penetration. A measured or known quantity of the refined asphalt is first placed in the fluxing tank, where it is heated to a fluid condition. A measured quantity of hot flux is then run in and the contents of the tank continuously agitated until asphalt and flux have combined to produce an asphalt cement of absolutely uniform consistency. When steam agitation is used special care is required to prevent condensation before it is injected into the bituminous material, or foaming will result. After melting or fluxing, the bituminous material is maintained at the proper temperature until used in the mix. Tanks should be provided with suitable stationary thermometers for registering the temperature of the bituminous material.

242. Proportioning the Constituents of the Mix. Final proportioning of the constituents of the mix is conducted from a mixing platform set above the mixer. Here the main aggregate, the filler if used, and the bituminous material are measured or weighed before placing them in the mixer. The mineral aggregate is usually run from the hot storage bin into a box where it is measured, in some cases by volume, but preferably and more accurately by weight, to the capacity of the mixer. If it has previously been separated into sizes, each size is separately measured in predetermined proportions. If the aggregate has been heated or stored in measured batches it is discharged directly into the mixer. Mineral filler may be measured in the same box as the rest of the aggregate, but as it is used in relatively small quantities it is usually measured in hand buckets and dumped directly into the mixer. The hot bituminous material is measured in a bucket preferably by weight. The bucket is usually suspended on trunions, which allows it to be readily moved from the charging pipe to the mixer into which it is emptied.

243. Mixing. There are a number of types of mixers, but the one most commonly used consists of an iron box equipped with a double set of blades revolving on two horizontal shafts extending through the box. These blades are so set that the mixture is continually tossed upward and at the same time worked toward the center of the mixer. The blades are spaced so as to efficiently mix a given size aggregate and are detachable so that worn or broken blades may be replaced and different spacing may be facilitated by changing shafts. Such mixers are provided with a sliding discharge at the bottom which is controlled by a lever. Another type of mixer consists of a revolving drum equipped with a central spiral conveyor which is superimposed with another spiral conveyor operating in the reverse direction. After all of the constituents have been introduced into the mixer they should be mixed until the mineral particles are

thoroughly and uniformly coated with bituminous material. The finished mix is then dumped into wagons or wheelbarrows and conveyed directly to the site of construction.

244. Transportation of the Mix to the Road. It is essential that the bituminous mixture be delivered on the road at such temperature that it may be readily spread and compacted. As this temperature is approximately that required for mixing, precautions should be taken to prevent rapid cooling of the mix after being discharged from the mixer. If the construction work is at any considerable distance from the plant, each load should be protected while in transit by a canvas cover. Carts, trucks or wagons used for transporting the mix should preferably be provided with sheet metal linings. If not, they should be kept whitewashed or oiled on the inside to prevent the mix from sticking to them when dumped on the road.

INSPECTION DETAILS

245. Characteristics of Mineral Constituents. (*a*) The plant Inspector is not expected to make tests of quality of the mineral constituents which may be covered in specifications, as such tests are made by the laboratory. Visual examination should be made, however, in connection with certain physical characteristics of the various products. If broken stone is to be used, the rock is usually approved upon laboratory tests made in advance of the work, in which case the Inspector will find it convenient to secure a hand specimen from the sample tested to visually compare with material furnished. In the case of slag, if the weight per cubic foot is specified, a determination of this property (§ 375) should be made on a sample from each shipment, or, if delivered in wagons, for approximately each 50 cubic yards. The quality of gravel pebbles should be tested from time to time by means of a hammer (§ 374). All aggregates should be examined to see that they are free from dirt or

extraneous material and thin splintery fragments, and that the individual particles are not covered with a coating of clay or loam which will prevent proper adhesion of the bituminous cement to their surfaces. Sand should be examined to see that it is composed of hard reasonably sharp quartz grains.

(*b*) Size or grading tests (§ 371) should be made on samples taken from each shipment of aggregate and if marked variations occur between different shipments of presumably the same product they should be stored in separate piles. If the mineral constituents are delivered by wagons a sample should be tested for grading for approximately each 50 cubic yards received.

246. Consistency and Bitumen Content of Bituminous Material. (*a*) The only test of bituminous cement which the Inspector is required to make is that of consistency. In the case of refined tar the float test (§ 379) is used, and in the case of asphalt and asphalt cements the penetration test (§ 378) is used. Representative samples from each shipment of bituminous cement should be tested for conformity with the specification requirement for consistency immediately upon its arrival. In addition, a test for consistency should be made early in the morning upon each tank of melted material which has been heated over night. Prolonged heating, particularly if accompanied by violent agitation, may materially harden the product. For this reason low heat and gentle agitation is advisable when the melted material is being carried over from one day's work to another.

(*b*) When refined asphalt is to be fluxed at the plant it is necessary to ascertain to what extent the addition of a given proportion of flux will increase the penetration of the asphalt. This will largely depend upon the relative consistency of asphalt and flux and no definite rule can be given which is applicable to all cases. Proportions are expressed in pounds of flux per 100 of R.A. (refined asphalt),

and for those products ordinarily handled at a paving plant it will usually be found that one pound of flux will increase the penetration of 100 pounds of R.A. from 2 to 4 points. In general, the harder the R.A and the more viscous the flux, the greater will be the proportion of flux required to produce an A.C. (asphalt cement) of given penetration. A fluxing curve such as shown in Fig. 26 will be found useful as a guide to regulating proportions of A.C. and flux.

Such a curve should be obtained from the laboratory or made by the Inspector from penetration tests upon small

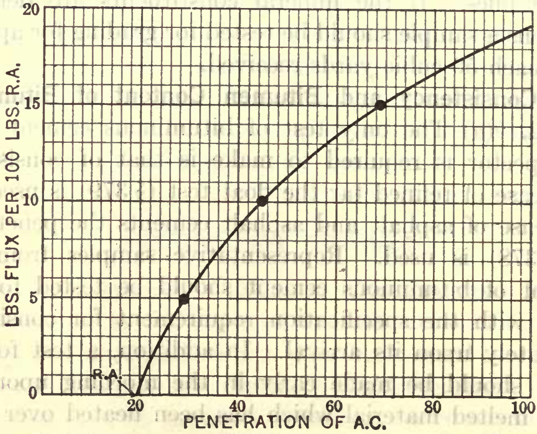

Fig. 26. Example of Fluxing Curve

amples of A.C. prepared by combining different proportions of R.A. and flux. The penetrations of A.C. are plotted against the proportion of flux and R.A. and when connected by a continuous line indicate what penetrations may be expected from intermediate proportions. Owing to different hardening conditions during the fluxing process in the plant and on small laboratory samples, such a curve may not give absolutely correct values for plant control, but a rather definite relation may be established after a few comparisons have been made.

(c) When fluxing at the plant it is necessary to keep track of the weight of melted asphalt in the tank. The weight per gallon of flux should also be ascertained either by direct test or from a report of its specific gravity (Fig. 7) when the proportion of flux is to be measured by volume rather than by weight. If a fluxing curve is available the proper proportions of flux is at once indicated. If not, a trial will have to be made. Thus it may be assumed that one pound of flux will increase the penetration of 100 pounds of R.A. 3 points. If it is desired to raise the penetration of the asphalt 18 points, then $\frac{18}{3}$ or 6 pounds of flux will be added to each 100 pounds of R.A. After thorough combination the resulting A.C. should be tested for penetration. The average increase in penetration actually produced by each pound of flux per 100 pounds of R.A. should then be ascertained. For this purpose the following formula may be used, where x equals the increase in penetration produced by 1 pound of flux to 100 pounds of R.A., a equals the number of pounds of R.A. in the tank, b equals the pounds of flux which was added, c represents the penetration of the original R.A., and d the penetration of the resulting A.C.

$$x = \frac{a(d-c)}{100b}.$$

The value of x thus determined may be used to ascertain the amount of flux required to prepare new batches by means of the following formulas in which the letters a, b and c represent the same factors as in the preceding formula and e equals the desired penetration.

$$\text{Pounds of flux required} = \frac{a(e-c)}{100x}.$$

If the trial operation produces an A.C. of lower penetration than desired, then more flux should be added. If on the other hand the resulting A.C. is too soft more R.A. must be added to the contents of the tank. The following formulas may be used to correct the trial batch if the desired

penetration was not secured. In each of these formulas the letters represent the same factors as in the preceding formulas:

When penetration of the trial batch is too low, additional

$$\text{pounds of flux required} = \frac{b(e - d)}{d - c}.$$

When penetration of the trial batch is too high additional

$$\text{pounds of R.A. required} = \frac{a(d - e)}{e - c}.$$

(*d*) When sampling newly fluxed asphalt it should be remembered that considerable time may be required to effect complete combination, particularly if the R.A. has a very low penetration. In a paving plant the main fluxing operation is usually conducted at the end of a day's work and a sample taken and tested the following morning. Slight corrections in consistency usually require a half hour or so to complete, but if any doubt exists regarding the completion of the fluxing process it is well to test the consistency of two samples taken from the tank at different levels. In case the product contains a considerable amount of nonbituminous material, thorough agitation is necessary to prevent settlement not only through the fluxing process, but while it is being withdrawn for use. In such cases it is advisable to occasionally test samples from different levels in the tank to determine if the product is of uniform consistency and is, therefore, approximately uniform in composition. If not, more active agitation is required.

(*e*) When an oil asphalt is fluxed the amount of bitumen in the A.C. may be considered as 100 per cent, as both R.A. and flux consist of practically pure bitumen. When a refined native asphalt is fluxed, however, it is necessary to consider the percentage of nonbituminous material which it contains in order to ascertain the percentage of bitumen in the resulting A.C. This may be determined by means of the following formula, in which x equals the per cent of

bitumen in the A.C., p equals the per cent of bitumen in the R.A., and a equals the pounds of flux per 100 pounds of R.A.

$$x = \frac{100p}{100 + a}.$$

247. Control of Temperatures. Temperature control at a paving plant is of great importance, first to prevent injury of the constituents of the mix by overheating; second, to make it practicable to secure a uniform mixture of such consistency that it may be readily spread and uniformly compacted on the road. The temperature of the mineral aggregate as it leaves the drier should be watched and special attention paid to its temperature as discharged from the hot storage bin. The temperature to which the bituminous material is heated in the melting and drawing off tanks should be carefully regulated and that of the finished mix, as it is discharged from the mixer and leaves the plant, should be noted from time to time. Mineral aggregate should be heated sufficiently to thoroughly dry it and facilitate the coating of each particle with the requisite amount of bituminous material, but not so high as to injure the bituminous coating or cause it to partially drain off when dumped from the mixer. The bituminous cement should be heated sufficiently to make it pour readily, but not so high as to cause undue loss by volatilization, hardening, or burning. The proper temperature limits to be observed vary with the types of materials used and character of the paving composition and should be covered by specification requirements. The following may, however, serve as a general guide:

	Degrees F.
Mineral Aggregates:	
For mixing with refined tars	150–250
Coarse aggregates for mixing with A.C.	200–300
Aggregate passing $\frac{1}{2}''$ screen for mixing with A.C.	250–350

Bituminous Materials:

Refined tar	225–275
Asphalt Cement	275–350

Mixtures:

Containing tar	150–200
Coarse aggregates containing A.C.	200–300
Aggregates passing $\frac{1}{2}''$ screen and containing A.C.	250–350

248. Measurement and Control of Proportions. (*a*) The proportions of the constituents of bituminous mixtures are sometimes specified upon a volume basis, but more frequently by weight. Volume proportions are the most logical, in view of common variations in specific gravity of the different types of mineral aggregates, and bituminous materials allowed under a single specification, but weight proportions are the most accurate to make and, with any given set of constituents, will produce the most uniform mixture. Gradings are always specified and determined upon a weight basis.

(*b*) The simplest type of bituminous concrete is one composed of a single commercial broken-stone product and asphalt cement or refined tar. The size or grading of such a product need only be determined upon samples taken from shipments received or from storage piles at the plant. For this type the proportion of bituminous material to aggregate is often specified as a definite range in gallons per cubic yard, the exact quantity to be as determined by the Engineer. The allowable variation in number of gallons per cubic yard is sufficiently wide to care for variations in the bitumen content of the bituminous materials allowed to be used. In such cases the exact proportions to be used for the materials furnished on the job is decided upon the appearance of the mix and its behavior on the road during spreading and compaction. When once fixed, volume pro-

portions may be translated to weight proportions if desired and measurement thereafter made by weight.

(*c*) A second type of bituminous concrete contains an aggregate composed of two or more products such as broken stone and sand, the grading limitations of each being specified together with the volume proportions in which they are to be combined. When these factors are properly covered, the grading of the combined aggregate need not be specified or determined by the Inspector. He should, however, make grading determinations of the individual constituents and see that they are used in such proportions as are finally set by the Engineer; also that they are mixed with the proper proportion of bituminous cement as covered in the preceding paragraph.

(*d*) In a third type of bituminous mixture the grading of the main or total aggregate is specified without necessary reference to the grading of the individual products which may be required to produce the final aggregate. In such cases the Inspector should sample and test the aggregate from the mixing platform as it is delivered to the mixer, at least once a day and more often if the necessity is indicated. In addition, it will be necessary for him to test the grading of each aggregate constituent so that they may be combined in such proportions as to produce the specified grading (§ 250). In this type the proportioning of the bituminous materials should always be made upon a weight basis with due allowance for nonbituminous impurities which may be present so as to secure the proper percentage of bitumen in the mix.

(*e*) The proportions of aggregate and bitumen to be used in a given mix are sometimes specified upon a percentage basis of the mineral aggregate and sometimes upon a percentage basis of the combination. The difference between these two methods should be clearly understood by the Inspector. Thus, if bitumen is to be added to the extent of 10 per cent of the aggregate, then 10 pounds of bitumen

are added to each 100 pounds of aggregate and the percentage of bitumen in the mix will be

$$\frac{10}{100 + 10} = .091 \text{ or } 9.1 \text{ per cent.}$$

If on the other hand the mix is specified to contain 10 per cent bitumen, then 10 pounds of bitumen should be combined with every 90 pounds of aggregate or 11.1 pounds with every 100 pounds of aggregate. If the bituminous material contains nonbituminous impurities and the percentage of bitumen is expressed on the basis of the mineral aggregate, then the number of pounds of bituminous material required for each 100 pounds of aggregate is obtained by one of the following formulas in which x equals the number of pounds of bituminous material required for each 100 pounds of aggregate and b equals the per cent of bitumen in the bituminous material.

(*a*) a = the per cent of bitumen required on the basis of the mineral aggregate.

$$x = \frac{100a}{b}.$$

(2) a = the per cent of bitumen required in the combined mixture.

$$x = \frac{100a}{b - a}.$$

(*f*) The addition to the mix of mineral filler consisting of finely pulverized rock or Portland cement is often specified on the same basis as for bitumen, described in the foregoing paragraph. The effect of mineral filler, which is to fill the very small voids and toughen the mix, is due to that portion which is sufficiently fine to pass the 200-mesh sieve. Its addition is, therefore, frequently made upon the basis of the per cent of material finer than 200 mesh which it contains. Sand particles in the main aggregate which pass the 200-mesh sieve are not usually considered as filler proper

and may be ignored in calculations for the addition of filler. The finely divided mineral matter in Trinidad asphalt, or the free carbon in tars may, however, be considered as a substitute for mineral filler, in which case an allowance should be made in calculating filler on a weight basis. The formulas which may be used under such circumstances to ascertain the number of pounds of bituminous material and mineral filler to add to each 100 pounds of aggregate are given below, where the letters have the following significance.

x = pounds of bituminous material per 100 pounds aggregate.
a = per cent of bitumen desired in the mix.
b = per cent of bitumen in bituminous material.
y = pounds of mineral filler per 100 pounds aggregate.
l = per cent of filler passing 200-mesh desired in the mix.
m = per cent particles passing 200 mesh in filler.

$$x = \frac{100am}{a(100 - m) + b(m - a - l)}.$$

$$y = \frac{100[b(l + a) - 100a]}{a(100 - m) + b(m - a - l)}.$$

(*g*) When weighing the proportions of the individual constituents of a mix the Inspector should see that the tare of both weighing box and bituminous material bucket are accurately obtained and the tare weight or balance properly set, or added to the total weight. Tare weights should be checked from time to time and, in the case of the bituminous material bucket, at least once an hour during use, owing to the more or less constant accumulation of hardened bituminous material. Both scales and bucket should be cleaned every day.

249. The Combination of Aggregates. (*a*) In connection with proportioning two or more constituents of an aggregate, it is desirable to approach as closely as possible a standard grading which may either be stated in the specifications or may be considered as the average of the grading

limitations. For the purpose of illustration the following table presents a simple problem:

Requirement No.	Sieve Tests	Available Products A	Available Products B	Specification Limits	Standards
1	Pass. 10-mesh, ret. on 40 mesh	15	50	12–50	23
2	" 40 " " " 80 "	80	10	15–68	43
3	" 80 " " " 200 "	5	40	20–40	34

In this table are shown the gradings of two sands, *A* and *B*, together with the specification limits for grading which any combination of the two must meet and a standard grading which should be approached as closely as possible. First of all, it should be noted that neither sand by itself comes entirely within the specification limits. With regard to requirement No. 1, both sands fall within the specified limits and, therefore, any combination will also meet the specifications. With regard to requirement No. 2 neither sand meets the specification requirements but, as one is above and one below, a satisfactory combination is possible. If both were above or both below, a combination could not, of course, be made to fall within the specifications. With regard to requirement No. 3, as one is below and one is within the specifications, a satisfactory combination is again indicated. It is now necessary to ascertain the range in proportion of the two sands which will fall within the specifications, and what combination will most closely approach the standard. This problem may be solved by trial proportions but better algebraically. All possible combinations may be considered as consisting of 100 parts, and the proportion of either constituent calculated as parts per 100 of the combination as follows: Thus, under requirement No. 1 the percentage of sand *A* in combination with sand *B* required to give the standard grading is calculated from the following formula, where x equals the number of parts per

100 of the combination, a equals the grading percentage of sand A, b equals the grading percentage of sand B, and c equals the desired grading percentage of the combination.

$$x = \frac{100(c - b)}{a - b}.$$

In this case

$$x = \frac{100(23 - 50)}{15 - 50} = \frac{-2700}{-35} = 77.1.$$

From this result it is evident that 77 parts of sand A and 100 − 77 or 23 parts of sand B will produce under requirement No. 1 the standard grading of 23. By applying this formula logically to each of the specification limits and to the standard grading for each requirement, it is possible to construct a table showing the range in parts per 100 of sand A which can be used with sand B and produce a combination within specification limits, and from this range it is possible to pick the combination which will most closely approach the standard.

Requirement No.	Parts of Sand A per 100 Parts Combination	
	Range within Specification Limits	Meeting or Closest to Standard
1	0 to 100	77
2	7 to 83	47
3	0 to 57	17

In connection with the problem under consideration, it is seen from the table constructed that sand A may be used with sand B to the extent of from 7 to 57 parts per 100 of combination to meet the specification requirement. Within these limits it is evident that requirement No. 1 of the standard cannot be met. By averaging the values in this table for the three standard requirements 47 is obtained, which happens to meet requirement No. 2. Therefore, 47 parts of sand A and 53 parts of sand B will meet the specifi-

cations requirements and most closely approach the standard grading. In this case the proportions are so nearly the same that if measured volumetrically in small batches the proportion of 1:1 would probably be used.

(*b*) It sometimes happens that no two available constituents can be found to produce a desired grading, and a combination of three constituents may be necessary. Under these circumstances the formula given in the preceding paragraph may be applied to two of the products to obtain a combination as close as possible to the specification requirements. Such combination is then considered as a single product and its combination with a third product next taken up. Thus, suppose that three sands, A, B and C, are available but that no combination of two sands will meet the specifications. Certain requirements may, however, be met by combining sands A and B in the proportions of 1:3. It is next found that this product may be combined with sand C in the proportions of 1:2 so as to meet specifications. The proportions of $A:B:C$ will then be $1:3:2(1+3)$ or $1:3:8$.

250. Characteristics of Mix. The first consideration in connection with a bituminous mixture is that it shall be uniform. There should be no noticeable segregation of any of the constituents and each particle of aggregate should be thoroughly coated with bitumen. Uniformity can only be secured by carrying on the mixing process for a sufficient length of time. The exact time necessary will depend upon the type of mixer and its method of operation. Under ordinary conditions one minute will be required for aggregates containing 25 per cent or more of material passing the 10-mesh sieve. If the aggregate is exceedingly fine, as in the case of earth mixtures, $1\frac{1}{2}$ to 2 minutes may be required, while $\frac{1}{2}$ minute may be sufficient for aggregates containing little or no material passing a 10-mesh sieve. When discharged from the mixer the mix should tend to crawl but not flow or remain stationary in a pile. This will depend upon its temperature and the percentage of bitumen which

it carries. If the mix is sloppy, either too high a temperature or too much bitumen is indicated. If stiff, dry, and lusterless in appearance a deficiency of bitumen should be suspected unless marked overheating has occurred, in which case it may evolve blue or yellowish fumes according to whether an asphalt or tar binder has been used. The temperature of the mix should be frequently taken and recorded by the Inspector. In the case of sheet asphalt mixtures a pat test (§ 380) should, in addition, be made from time to time as a check on proper proportions. Daily samples of the mix should also be taken and forwarded to the laboratory for check on proportions and grading. The condition and behavior of the mix on the road, during spreading and compaction, will often indicate the necessity for slight modifications in proportions and temperature, which cannot be told by inspecting the mix at the plant. For this reason the plant Inspector should coöperate to the fullest extent with the street Inspector.

251. Output of the Plant. The rated batch capacity of a mixer given in cubic feet will not hold good for all types of mixes, but, for a given job with known batch weights, the yardage of pavement which should be laid by each load is soon ascertained, provided the number of batches to the load is kept constant. The plant Inspector should, therefore, keep a daily record of the number of loads produced and thus check the yardage of pavement laid as measured by the street Inspector. As described under the individual types of pavement (§ 262) it is quite possible to calculate, with reasonable accuracy, the number of square yards which a load should lay or, in other words, the weight per square yard of pavement of a specified thickness.

252. Coöperation of Inspectors. It is quite necessary that the plant Inspector should coöperate to the fullest extent with the street Inspector, the Laboratory and the Contractor. The way the mix handles on the street is often an important guide to desirable modifications which may be

made, within specification limits, in heating and proportioning the mix. If possible, the plant Inspector should occasionally visit the street to observe conditions but whether or not this is done, he should always keep in touch with the street Inspector. The one will, therefore, serve as a guide and check to the other. In like manner the plant Inspector should submit suitable samples of the constituents and of the mix proper to the Laboratory for check and control tests on plant operation. While material violations of specification requirements for plant operation and output will warrant rejection of the mix, the Inspector should bear in mind the fact that economical operation of the paving gang is dependent upon the rate of supply and amount of mix delivered by the plant. If, therefore, slight variations from specifications occur which make the matter of rejection of doubtful necessity, the proper correction should be made at once, but the mix already turned out may be allowed to be laid with the understanding that, if later considered unsatisfactory by the Engineer, it shall be removed and replaced at the expense of the Contractor. In such cases the exact location of the doubtful mix in the pavement should be ascertained and recorded.

INSPECTOR'S EQUIPMENT

253. The Plant Laboratory. At the paving plant a small room should be assigned the Inspector for conducting necessary control tests. This room should contain a stout work bench for testing apparatus, shelves for samples and containers, a chair and table. The exact testing equipment which may be needed will depend somewhat upon the type of mix which is to be produced, as indicated in the following list:

For Sampling,

A supply of close-woven bags for shipping samples of aggregate to the laboratory.

A ball of stout twine.

A supply of eyelet tags for identification information.

A long-handled metal dipper.

A supply of 1-quart tin cans.

A supply of 3-oz. round tin boxes.

A supply of gum labels.

For Testing:

A set of standard screens and sieves as may be called for in specification requirements (§ 371).

A stiff brush for cleaning sieves.

A spring balance with pan capacity of 10 pounds (§ 371) for screen analysis of coarse aggregates if used, or a beam balance of similar capacity and set of decimal weights.

A spring balance with pan capacity of 200 grams (§ 371) for screen analysis of fine aggregates, if used, or a sand scale of similar capacity.

A complete penetration test outfit (§ 378) if asphalt cement is used.

A complete float test outfit (§ 379) if refined tar is used.

A complete pat test outfit (§ 380) if sheet asphalt mix is used.

A small pocket magnifying glass.

A hand sample of approved rock for visual comparison if broken stone is used.

For Records and Reports:

A scratch pad and pencil.

A supply of report forms (§ 395).

A carbon paper for duplication of reports.

254. Personal Equipment. The Inspector should carry with him for general use the following articles:

A pocket rule (§ 387).

An armored thermometer (§ 386).

A diary and pencil.

CHAPTER XIII

INSPECTION OF BITUMINOUS CONCRETE AND SHEET ASPHALT PAVEMENTS

GENERAL CHARACTERISTICS

255. Types of Pavement. Bituminous concrete and sheet asphalt pavements are composed of a mixture of mineral aggregate and bituminous material prepared as a paving composition and laid as such upon a suitable foundation. They may conveniently be considered under the following seven classes:

I. One-size stone bituminous concrete, in which the mineral aggregate consists of a single commercial size of crusher product with no exact grading limitations.

II. Coarse-graded aggregate bituminous concrete, in which the mineral matter consists of a combination of coarse and fine aggregates so proportioned that the former predominates and the latter serves mainly as a void filling medium.

III. Fine-graded aggregate bituminous concrete, in which small size broken stone is mixed with sand in such proportions that the fine aggregate greatly predominates and thus separates the coarser stone fragments from intimate contact with one another.

IV. Asphalt block, in which a fine, carefully proportioned and graded bituminous concrete is molded under pressure into blocks. This type is considered under brick and block pavements (§ 315).

V. Sheet asphalt, which consists of a carefully proportioned mixture of graded sand, mineral filler and

asphalt cement, thus producing a dense homogeneous mortar.

VI. A natural bituminous sandstone or bituminous limestone suitably prepared for spreading as a bituminous mortar or mastic. The characteristics of the former variety are similar to sheet asphalt while those of the latter more nearly approach the bituminous earth type.

VII. Bituminous earth in which the mineral aggregate consists of finely divided soil, such as clay, with no well defined grading limitations.

256. General Method of Construction. The bituminous mixture, ordinarily prepared at a paving plant, is evenly spread upon the foundation so as to produce after compaction a wearing course of the desired thickness, usually about 2 inches. With the exception of certain rock asphalt preparations and mixtures, containing cut-back or emulsified asphalt or cut-back refined tar, the mixture is laid and rolled while still hot from the paving plant. On bituminous concrete which after compaction shows a surface of open texture the pavement may be given a seal coat of hot bituminous material, followed by a light covering of stone chips or sand which is forced into the surface voids by rolling. If the surface is of close texture the pavement is often finished off with a dusting of mineral filler. In the fine aggregate and sheet types of pavement, what is known as a binder course of bituminous concrete may be interposed between the foundation and pavement proper

DETAILS OF CONSTRUCTION APPLICABLE TO ALL TYPES

257. Foundations. Bituminous concrete and sheet asphalt pavements are commonly laid on a cement concrete foundation, the surface of which is slightly rough (§ 219*a*). They are sometimes laid upon a bituminous concrete

foundation and sometimes upon an old gravel or macadam road which is first prepared by patching (§ 173*b*) or resurfacing (§ 173*c*). Unless resurfacing is absolutely necessary, due to lack of thickness, such foundations should be disturbed as little as possible and the introduction of a binder course is, therefore, sometimes adopted for the purpose of truing up the surface to receive the pavement proper. The same is true when old Telford, cobble stone block, brick or cement concrete pavements are utilized as foundations. In general, irregularities in thickness of binder or wearing courses are to be avoided, however, so that in new concrete foundation construction it is important that the surface be true and carry the same crown as the finished pavement. Sometimes a thin paint coat of cut-back bituminous cement is applied to the carefully cleaned surface of the concrete foundation for the purpose of bonding the pavement to the foundation.

258. Preparation of the Bituminous Aggregate. (*a*) The bituminous aggregate is usually prepared at a paving plant from which it is delivered on the job by wagons, carts or trucks. Hand mixing, with preheated aggregate and bituminous cement, is possible for the large aggregate concretes but neither as satisfactory nor economical as properly conducted mechanical mixing. In place of the regular paving plant, for the cheaper types of construction, more or less successful attempts have been made to utilize the batch type of concrete mixer, in which the aggregate is sometimes heated by means of a large gasoline torch before the bituminous material is introduced. Accurate control of temperature and proportions is, however, difficult to secure unless the mixing operation is conducted at a paving plant proper (§ 237). The same factors which govern paving plant inspection, of course, apply to the preparation of the mix by the methods above described, and inspection of such work should approach as closely as practicable that of paving plant inspection.

(*b*) For some types of work cut-back bituminous cements or emulsified asphalts are mixed with unheated mineral aggregate either by hand or in ordinary concrete mixers. Such bituminous concrete is, however, more commonly used for patching than for straight construction.

259. Function and Characteristics of Mineral Filler. (*a*) Many specifications for bituminous concrete, and practically all specifications for sheet asphalt, require the addition of mineral filler to the mix during preparation. While a great many finely divided mineral substances have been utilized as filler, those most commonly specified and used are limestone dust and Portland cement. These products have, in general, been found most satisfactory because of their availability, the ease with which they may be combined in the mix without balling up, their extreme fineness and the toughening effect which they produce upon the mix. Specifications for fineness of limestone dust, including also dolomite dust (§ 199), usually require 100 per cent to pass the 30-mesh sieve and at least 66 per cent to pass the 200-mesh sieve. The same requirements are made for Portland cement filler although this material under the standard specifications will show at least 78 per cent passing the 200-mesh sieve. All mineral filler should, of course, be perfectly dry when used.

(*b*) The voids in loose dry filler vary greatly according to the type of filler, its degree of fineness and method of handling. Consequently, a given weight does not represent a constant loose volume. In proportioning it is, therefore, preferable to measure filler by weight rather than by volume in order to secure a uniform mix. It should not be forgotten, however, that one of the objects of using a filler is to fill voids, so that the volume of space occupied by the filler is of considerable importance. When present in a compacted mix, both limestone dust and Portland cement filler may be assumed to contain 40 per cent voids. As they are equivalent in this respect, equivalent volumes will be

represented by different weights and percentages of the mix, depending upon their difference in specific gravity. This fact should be borne in mind when proportioning by weight. Thus, the specific gravity of Portland cement is 3.1 while that of limestone is about 2.7. Therefore, in a mix 2.7 pounds of limestone dust is equal to 3.1 pounds of Portland cement as a void filler. One pound of limestone dust is equal to 1.15 pounds Portland cement and one pound of Portland cement is equal to 0.87 pound of limestone dust.

260. Spreading the Bituminous Aggregate. (*a*) Bituminous aggregates delivered from the mixing plant should arrive on the road at such temperature that they may be readily spread and compacted. The temperature of the loads as received should, therefore, be frequently ascertained by the Inspector. Before placing the mix, the foundation should be thoroughly clean and dry. Loads should never be dumped in place but should be shoveled from piles preferably deposited upon a dumping board. Each pile should be shoveled from the bottom and the mix deposited on the road by turning the shovel completely over. It is then spread by means of hot rakes to such thickness as, after compaction, will produce the specified thickness of pavement. The rakers should not stand on the hot mix more than absolutely necessary. When raking coarse graded bituminous aggregates, the largest fragments may tend to come to the top and if this tendency becomes too pronounced, accumulations of such fragments should be raked in advance of the layer so as to be completely covered when spreading the next load. All contact surfaces of curbs, gutters, manholes, etc., should be lightly but uniformly painted with hot bituminous cement in order to bond them to the mix. Measurement of loose and compacted depth of the hot mix may be made with a screw driver or stiff putty knife. The exact relation between loose and compacted thickness cannot be accurately foretold for any type of mix as this will depend upon the extent to which the par-

ticular mix fluffs up or settles during spreading. Control of thickness is better secured by ascertaining the yardage that each load of known weight should lay and measuring off the proper distance for each load on the curb or edging. This is determined from the weight per square yard of compacted pavement (Figs. 27 to 34). Depth of mix at the sides may be measured directly on the curbs, gutters or edging. Side protection by such forms of construction is highly desirable but sometimes the mix is laid and compacted between plank runners of suitable thickness laid along the sides of the road. After completion of the pavement proper, these runners may be moved to an advanced position and the bituminous aggregate protected by the construction of well-consolidated broken stone or gravel shoulders.

(*b*) As the behavior of the mix during construction will often indicate desirable modifications in its preparation at the plant, the street Inspector should keep in close communication with the plant Inspector and advise him of the temperature at which the mix is received on the road, whether it appears to be too sloppy or too dry, whether or not it is too stiff to rake properly, or tends to ball up, and how the surface closes up under compaction. Specifications frequently contain a clause relative to the minimum air temperature at which the pavement may be laid. In cold weather, therefore, the Inspector should record air temperatures during progress of the work.

261. Compacting and Finishing. Bituminous aggregates should be compacted by rolling, while hot, and as soon as possible after spreading and raking. If allowed to cool or set up before rolling, satisfactory compaction cannot be obtained. While the ordinary three-wheel road roller is sometimes used for coarse aggregates, the use of tandem rollers is to be preferred for fine aggregates. Initial compaction is sometimes secured by the use of a roller of light weight and final compaction with a heavier roller, usually from 7 to 8 tons in weight. If the mix tends to adhere to the wheels of

the roller they should be mopped with kerosene and water during the rolling operation. Rolling should commence at one side parallel to the curb or edging and each trip of the roller should overlap the preceding one until the center line of the road is reached, when the operation is repeated, starting at the other side. The roller should proceed slowly and alternate trips should be of slightly different length to prevent wave deformation of the surface. If the pavement is of sufficient width, the second rolling is made diagonally across the center line and later followed by cross rolling. Places which cannot be reached with a roller should be compacted and finished with hot tampers and smoothers. Unless a coarse aggregate is being laid as wearing course, to be followed with a seal coat, or as binder course, the surface of a well-proportioned mix should close up under rolling. Spots which do not close up may require finishing with hot smoothing irons, but great care should be exercised that the mixture is not burned by such treatment, or scaling of the surface under traffic will result.

(*b*) Rolling should be conducted as continuously as possible to avoid the formation of numerous joints. When the operation is temporarily discontinued, as at the end of a day's work, the last load may be rolled to a featheredge in which case, when work is resumed, the mix should be cut back so as to produce a slightly beveled edge for the full thickness of pavement. The material which has been cut back should then be removed from the work and new mix laid against the fresh cut. A better method of forming joints consists of rolling into the hot mix a stout rope which is laid across the pavement close to the finishing edge. This rope is allowed to remain in place until work is resumed when it is removed, together with all surplus material on the far side, and fresh mix is then laid against the joint thus formed. Sometimes the edge of a joint is painted with hot bituminous cement but this practice is apt to lead to the formation of an undesirable fat streak across the pavement.

(*c*) After final compaction the surface of a close mix pavement is usually finished by a sweeping with limestone dust or Portland cement. An intermediate or binder course (§ 278) is purposely left with a slightly open surface and should be clean and free from dust or dirt when the pavement proper is laid upon it. Coarse aggregate bituminous concrete pavements, as a rule, have a somewhat open surface and are usually completed with a surface treatment or seal coat of bituminous cement applied and covered the same as in bituminuous macadam construction (§ 198). Hand pouring, or small mechanical distributors, are used for this purpose together with a squeegee. Sometimes the surface voids are filled with a very light application of a bituminous sand mixture, prepared at the paving plant, instead of with the ordinary seal coat. In such cases the bituminous sand aggregate while hot is spread over the surface and rolled in so as to produce a layer of not over $\frac{1}{4}$ inch in thickness.

262. Measurement. Bituminous concrete and sheet asphalt pavements are commonly paid for upon a square yard basis complete in place. The Inspector should, therefore, make measurements of length, width and depth and in addition record the number of loads or weight of mix used, as a check upon such measurements. Thus, if the weight per load is known as well as the weight per square yard of pavement, the length of pavement which each load should lay is ascertained from the following formula. In this formula x equals length in inches which should be laid by one load, a equals width of pavement in feet, b equals weight of load and c equals weight of pavement per square yard.

$$x = \frac{108b}{ac}.$$

If x equals the length in feet instead of inches, then

$$x = \frac{9b}{ac}.$$

Sometimes the bituminous cement is paid for as a separate item but, except for paint coat and seal coat work, the plant Inspector should ascertain the amount used from his inspection of the mix. Measurements by volume or weight of materials used in seal coat work should be made as a check upon the added thickness of pavement due to such seal coat as in the case of bituminous macadam (§ 204). Under the various types of pavements in the following paragraphs diagrams are shown which may be of service to both plant and street Inspectors, in connection with the measurement of materials in the mix proper.

263. Sampling. Samples of the constituents of the mix, and also of the product turned out by the mixer, are taken by the plant Inspector. Occasional check samples of the mix as received upon the work should be taken by the street Inspector and forwarded to the laboratory. In addition, it is highly desirable to take samples of the finished pavement both for laboratory analysis as to proportions and for density determinations. Such a sample measuring about one foot square should be carefully cut with an ax from each 10,000 square yards, and fractional area over this amount of pavement, extending through its entire depth before any seal coat is applied. The compacted depth is measured at the point from which the sample is removed and the exact location recorded. Each sample should be very carefully packed for shipment to the laboratory so that it will be received intact. Cover for seal coat should be sampled and tested exactly as for bituminous macadam work (§ 205). A sample of asphalt for paint or seal coat should be taken from each shipment received on the work.

ONE-SIZE STONE BITUMINOUS CONCRETE

264. The Mineral Aggregate. The mineral aggregate for one-size stone bituminous concrete consists of a single

size of crusher product, carrying little or no fine aggregate and with no exact grading limitations. It, therefore, produces what is commonly known as an open mix, which requires a seal coat. The rock itself should possess the same general characteristics as for bituminous macadam construction (§ 199*a*) although reasonably high toughness is of greater importance owing to the fact that little excess bitumen is present, in the pavement, to bond and hold in place fragments which may be fractured by the impact of traffic. Typical specifications of the U. S. Bureau of Public Roads require a minimum French coefficient (§ 28) of wear of 8 and a minimum toughness (§ 29) of 8 for the rock. The size or grading required in these specifications is as follows:

Aggregate	Per cent
Passing 1-inch screen, not less than......	95
Total passing $\frac{3}{4}$-inch screen.............	25–75
Retained on $\frac{1}{4}$-inch screen, not less than..	85
Chips for Seal Coat	
Passing $\frac{1}{2}$-inch screen, not less than......	95
Retained on $\frac{1}{2}$-inch screen, not less than..	85

265. The Bituminous Material. Asphalt cements (§ 96) or refined tars (§ 103) are used as binders for this type of construction. For each class of material the same consistency of product is used for both mix and seal coat. Sometimes, however, asphalt cement is used for seal coat when tar is used in the mix. As in bituminous macadam construction the most desirable consistency of bituminous cement will depend mainly upon climatic conditions but may also be influenced by traffic and the quality of stone used. In general, somewhat harder cements are used than for bituminous macadam, subjected to the same climatic conditions, as illustrated by the following requirements of typical specifications of the U. S. Bureau of Public Roads. Fluxed native asphalts, containing more than 6 or 7 per cent of nonbituminous material (§§ 96*c*, 133) are seldom used

in this type of work but refined tars may contain as high as 20 per cent or more of free carbon (§ 102*c*). The percentage of total bitumen as well as the specific gravity of the bituminous material are, of course, important considerations to the plant Inspector, when proportioning a mix upon a weight basis although for this type of pavement the presence of as high as 5 per cent of impurities may usually be ignored. Various other characteristics commonly specified are shown under Typical Material Requirements (§§ 411, 412).

General Climatic Conditions	Asphalt Cement	Refined Tar
	Penetration @ 25° C.	Float Test @ 50° C.
Northern U. S.	80–90	120–150 seconds
Southern U. S.	70–80	150–180 seconds

266. The Mix. (*a*) Specification limits for the proportion of constituents in the mix usually require from 18 to 21 gallons of bituminous material per cubic yard of broken stone or on a weight basis from 5 to 7 or 8 per cent of bitumen in the mix. For an aggregate coming within the typical limits of grading (§ 264) approximately 19.8 gallons per cubic yard will be required. Voids if measured by volume in the loose stone may be assumed at 45 per cent and in the compacted stone as 30 per cent without figuring in the space occupied by the bitumen. Upon this basis Fig. 27 shows the number of pounds of constituents per square yard of compacted mix 2 inches thick, which is the depth ordinarily laid. If the surface of the foundation is not rigid or is uneven, somewhat greater quantities will be required. The effect of variations in specific gravity of the constituents of the mix upon the weight of pavement per square yard is clearly shown in these diagrams, as well as the effect of impurities on the amount of bituminous material required.

(*b*) This diagram is not only useful as a guide to proportioning the mix by weight but also in determining the length of pavement that should be laid by each load of known weight. Thus, if the specific gravity of the rock is 2.7 and

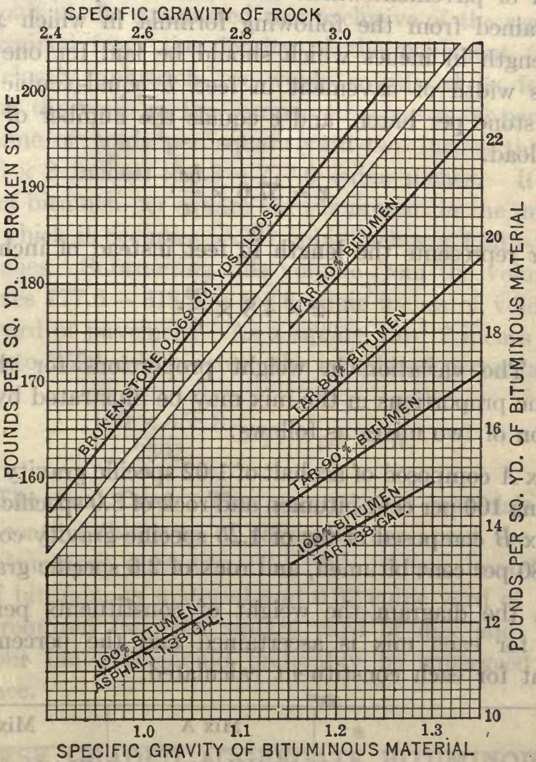

Fig. 27 Quantities of Materials Required for Construction of One-size Stone Bituminous Concrete

that of the bituminous material 1.05 with no impurities present, it is ascertained from the diagram that 175.4 pounds of rock and 12.1 pounds of bituminous material should be present in each square yard of pavement. The total weight of pavement per square yard is, therefore, 187.5 pounds.

This weight may be used in the formula given under measurements (§ 162) for determining the length of pavement which should be laid with each load of known weight.

(*c*) If proportions are measured by volume only then the length of pavement which should be laid per load may be ascertained from the following formula in which x equals the length in inches which should be laid for one load, a equals width of pavement in feet, b equals cubic feet of loose stone per batch, and c equals the number of batches to a load.

$$x = 57.6 \times \frac{bc}{a}.$$

If x represents the length in feet instead of inches, then

$$x = 4.8 \times \frac{bc}{a}.$$

(*d*) The variation in weight proportions for the same volume proportions in the mix may be illustrated by a comparison of two mixes as follows:

Mix *A* composed of asphalt of 1.02 specific gravity containing 100 per cent bitumen and rock of 3.0 specific gravity.

Mix *B* composed of tar of 1.25 specific gravity containing 80 per cent bitumen, and rock of 2.6 specific gravity.

From the diagram the weight of constituents per square yard for each mix is ascertained and the percentage by weight for each constituent calculated.

	Mix A		Mix B	
	Weight	Per cent	Weight	Per cent
Bituminous Material.......	11.7 =	5.7	17.8 =	9.5
Broken Stone	194.5 =	94.3	169.0 =	90.5
	206.2	100.0	186.8	100.0

While mix *B* contains 9.5 per cent of bituminous material this figure should be multiplied by 0.8 to ascertain the actual

amount of bitumen present. When this is done mix B is found to contain 7.6 per cent bitumen by weight while mix A contains 5.7 per cent. There is, therefore, a difference of over 2 per cent by weight although the volume proportions are the same.

(*e*) Voids in the compacted mix exclusive of the seal coat as determined from the density of the pavement (§ 384) should closely approach the voids calculated as follows. Assuming the voids in the compacted stone as 30 per cent, the volume of voids per square yard two inches thick is, $(36 \times 36 \times 2 \text{ inches}) \times 0.3 = 777.6$ cubic inches. If 1.38 gallons of bitumen per square yard is present in the mix the volume which it occupies is 231 cubic inches $\times 1.38 = 318.8$ cubic inches. Subtracting this volume from the volume of voids gives $777.6 - 318.8 = 458.8$ cubic inches of voids per square yard of pavement. As a square yard 2 inches thick amounts to 2592 cubic inches, the calculated percentage of voids is

$$\frac{100 \times 458.8}{2592} = 17.7 \text{ per cent.}$$

267. The Seal Coat. The quantities of materials used for seal coating this type of pavement are about the same as for bituminous macadam (Fig. 23). Approximately 0.4 gallon of bituminous material and 0.02 cubic yard of cover will be required for each square yard of mix laid. The bituminous material should preferably be squeegeed over the surface.

COARSE GRADED AGGREGATE BITUMINOUS CONCRETE

268. The Coarse Aggregate. The coarse aggregate for this type of pavement may consist of broken stone, broken slag or gravel. If of broken stone, it should possess the same physical characteristics as given for the preceding type of pavement (§ 264). Typical specifications of the U. S.

Bureau of Public Roads call for a French coefficient of wear of not less than 8 and a toughness of not less than 8. The same French coefficient may be specified for slag together with a maximum weight per cubic foot of not less than 65 pounds. It is particularly important that gravel, if used, be composed of sound durable pebbles and it should be carefully inspected from this standpoint by means of the hammer test (§ 374). Cover for seal coat is generally of the same type of material as coarse aggregate. Sometimes a bituminous sand mix seal coat is used, however, in which case the fine aggregate (§ 269) is used. Typical specification of the U. S. Bureau of Public Roads for grading of the coarse aggregate and seal coat cover are as follows:

Coarse Aggregate	Per cent
Passing 1-inch screen, not less than	95
Total passing $\frac{3}{4}$-inch screen	25–75
Retained on $\frac{1}{4}$-inch screen, not less than	85
Cover for Seal Coat	
Passing $\frac{1}{2}$-inch screen, not less than	95
Retained on $\frac{1}{4}$-inch screen, not less than	85

269. Fine Aggregate. The fine aggregate should preferably consist of hard, sharp, uncoated quartz sand although a mixture of sand, and stone or slag screenings is sometimes allowed. No rigid grading requirements are usually specified as dependence upon the stability of the mix is put upon the interlocking of the fragments of coarse aggregate which predominate. The fine aggregate should, however, be neither too coarse nor too fine. The U. S. Bureau of Public Roads typical specifications for grading are as follows:

	Per cent
Passing $\frac{1}{4}$-inch screen	100
Total passing 40-mesh sieve	30–70
Retained on 200-mesh sieve, not less than	90

270. The Bituminous Material. Asphalt cements (§ 96) are now ordinarily used as binders for this type of pavement although refined tars (§ 103) have been used to some extent. If used, the characteristics of the tars should be the same as stated under the one-size stone type of pavement (§ 265). Among the asphalt cements, those refined from petroleum and also fluxed Bermudez asphalt are most commonly employed. As the amount of bitumen, in the former, approximates 100 per cent, and, in the latter, 95 to 97 per cent (§§ 96*c*, 133) there is little need for taking the non-bituminous impurities into account when such asphalts are used. If refined tar or fluxed Trinidad asphalt are used, however, allowance should be made for non-bituminous impurities in connection with proportioning. The most desirable consistency of asphalt cement is slightly harder than for the one-size broken stone concrete under the same climatic conditions. Typical specifications of the U. S. Bureau of Public Roads require a penetration of from 70 to 80 for northern climates and from 60 to 70 for southern climates. Various other characteristics commonly specified are shown under Typical Material Requirements (§ 411).

271. The Mix. (*a*) The mix for this type of pavement may be proportioned in a number of different ways with the idea of producing a dense bituminous concrete, in which the coarse mineral fragments are brought into intimate contact and produce considerable mechanical stability, which is increased by the presence of fine aggregate in filling, as completely as possible, all interstitial voids. Sometimes the entire aggregate is screened into various sizes which are recombined, in such proportions as to produce maximum density. It is, however, generally satisfactory to consider the main aggregate as composed of only two constituents, coarse aggregate and fine aggregate. Mineral filler is ordinarily added to as great an extent as the mix will comfortably carry, without interfering with its workability. Upon

this basis weight proportions will usually come within the following limits:

	Per cent
Coarse aggregate	45–60
Fine aggregate	25–40
Mineral filler	3–5
Bitumen	6–8

Coarse aggregates retained on the $\frac{1}{4}$-inch screen and fine aggregates meeting the grading requirements given in the preceding paragraphs (§§ 267–268) may be assumed to contain 40 per cent voids compacted. In such case 40 parts by volume of fine aggregate will be required to fill the voids in 100 parts of coarse aggregate. The volume proportions of coarse to fine would then be $1:0.4$ or $2\frac{1}{2}:1$. While an excess of fine aggregate is undesirable, unless very dense in itself, more than the theoretical quantity is required to produce a close surface, owing to a certain amount of unavoidable segregation during spreading and raking. The most practical volume proportions will usually lie between 1.8 and 2 parts of coarse aggregate to 1 part of fine aggregate. Upon this basis and assuming the sand to have a constant specific gravity of 2.65, Fig. 28 shows the approximate number of pounds of each constituent required to produce one square yard of compacted mix, with a uniform thickness of 2 inches, taking into account normal variations in specific gravity and allowing for as high as 15 per cent of fine aggregate in the broken stone product.

(*b*) This diagram may be used as described for Fig. 27 (§ 266*b*) for determining weight per square yard and length of pavement which should be laid per load of mix of known weight (§ 162). If proportions are measured by volume the length of pavement which should be laid per load may be ascertained from the following formula in which x equals length in inches which should be laid for one load, a equals width of pavement in feet, b equals cubic feet of loose stone,

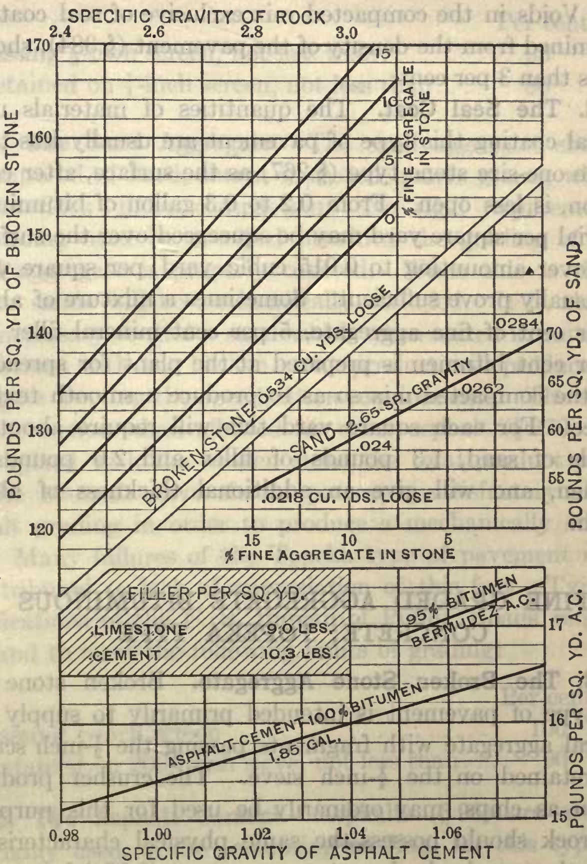

Fig. 28 Quantities of Materials Required for Construction of Coarse Graded Aggregate Bituminous Concrete

with 45 per cent of voids, per batch, and c equals the number of batches to the load.

$$x = 74.9 \times \frac{bc}{a}.$$

If x represents the length in feet instead of in inches then

$$x = 6.24 \times \frac{bc}{a}.$$

(*c*) Voids in the compacted mix exclusive of seal coat, as determined from the density of the pavement (§ 384), should be less than 3 per cent.

272. The Seal Coat. The quantities of materials used for seal coating this type of pavement are usually less than for the one-size stone type (§ 267) as the surface, after compaction, is less open. From 0.2 to 0.3 gallon of bituminous material per square yard may be squeegeed over the surface, and cover amounting to 0.015 cubic yard per square yard will usually prove sufficient. Sometimes a mixture of about 85 per cent of fine aggregate, 5 per cent mineral filler and 10 per cent bitumen is prepared at the plant for spreading over the compacted mix so as to produce a smooth texture surface. For each square yard this will require about 22 pounds of sand, 1.3 pounds of filler and 2.6 pounds of bitumen, and will give an additional thickness of about $\frac{1}{4}$ inch.

FINE GRADED AGGREGATE BITUMINOUS CONCRETE; TOPEKA TYPE

273. The Broken Stone Aggregate. Broken stone for this type of pavement is intended primarily to supply the mineral aggregate with fragments passing the $\frac{1}{2}$-inch screen but retained on the $\frac{1}{4}$-inch sieve. The crusher product, known as chips, may ordinarily be used for this purpose. The rock should possess the same physical characteristics as for the one-size broken stone pavement (§ 264) but sometimes no test limitations for French coefficient of wear or toughness are included in specifications. The use of fine gravel in place of broken stone is, in general, undesirable, although broken slag weighing not less than 70 pounds per cubic foot may be substituted. Typical specifications of the U. S. Bureau of Public Roads require the broken stone aggregate to meet the following requirements for size or grading:

	Per cent
Passing $\frac{1}{2}$-inch screen, not less than	95
Retained on $\frac{1}{4}$-inch screen, not less than	80

274. The Sand Aggregate. The sand aggregate should be composed of hard, sharp, uncoated quartz grains, which will interlock under compaction. No rigid requirements for grading need be specified provided the grading of the mixed aggregate is properly covered. When this is done inferior sands will be automatically excluded. It is, therefore, necessary to find a sand which when mixed in suitable proportions with the broken stone product will produce an aggregate meeting the specification requirements. The sand may be coarser than allowed for sheet asphalt (§ 279) but when mixed with the broken stone the total product passing the 10-mesh sieve should possess a satisfactory sheet asphalt grading in order to produce a mechanically stable mix. Many failures of the Topeka type of pavement may be attributed to lack of appreciation of this fact. Typical specifications of the U. S. Bureau of Public Roads require the sand to meet the following limits of grading:

	Per cent
Passing $\frac{1}{4}$-inch screen	100
Retained on 200-mesh sieve, not less than ...	90

275. The Asphalt Cement. Asphalts (§ 96) are almost invariably used as the cementing medium for this type of mix. The most desirable consistency of the asphalt cement is harder than for the preceding types under the same climatic conditions. Typical specifications of the U. S. Bureau of Public Roads require a penetration of from 60 to 70 for northern climates and from 50 to 60 for southern climates. If a fluxed native asphalt is used allowance should be made for non-bituminous impurities (§§ 96*c*, 133) in connection with proportioning the mix. While Trinidad asphalt cement may be used, most pavements of this type are constructed

with either an oil asphalt or fluxed Bermudez asphalt. Various physical and chemical requirements commonly specified for the asphalt cements are shown under Typical Material Requirements (§ 411).

276. The Mix. (*a*) In this type of pavement mechanical stability is largely dependent upon the grading of the aggregate, most of which is fine. For the material passing a 10-mesh sieve, sand is to be preferred to stone screenings and the same grading considerations should, in general, govern this part of the aggregate as control sheet asphalt grading. As the material passing a 10-mesh sieve predominates, the coarser particles may be considered as being individually suspended in the mixture without interlocking. From this standpoint the mix consists of a sheet asphalt aggregate carrying coarser particles which add nothing to its stability. As the pavement is not, however, ordinarily expected to withstand as severe traffic conditions as the maximum for sheet asphalt pavements, specification requirements for grading are not usually as rigid. They should, however, be made to approximate such requirements as illustrated by the following typical specifications, of the U. S. Bureau of Public Roads, for the total mineral aggregate including stone, sand and mineral filler.

Total Aggregate	Per cent
Passing ½-inch and retained on ¼-inch screen	5–10
" ¼- " " " 10-mesh sieve	11–25
" 10-mesh and retained on 40-mesh sieve	7–25
" 40- " " " 80-mesh sieve	11–36
" 80- " " " "200 " "	10–25
" 200- " sieve	5–11

In connection with the grading requirements for broken stone (§ 273) and sand (§ 274) aggregates, specification requirements should preferably make it necessary to use not less than 10, nor more than 30 per cent, of broken stone in the aggregate. The exact proportions to use can only be

ascertained from a complete sieve test on each of the constituents (§ 249). Such an aggregate when combined with the proper amount of asphalt cement should produce a mixture in which the bitumen will usually lie between 7 and 11 per cent and the mineral filler between 5 and 10 per cent. It will be noted that the amount of total aggregate, etained on the 10-mesh sieve, lies between 16 and 35 with an average of about 26 per cent. Assuming a fairly well graded sand all passing the 10-mesh sieve and containing 36 per cent voids when compacted, also assuming broken stone, all of which is retained on the 10-mesh sieve, and which contains 40 per cent voids when compacted, Fig. 29 shows the approximate weights per square yard two inches thick of the various constituents, when the volume proportions of sand to stone on the above basis are 3 : 1.

(*b*) If Trinidad asphalt is used in the mix it is ordinarily fluxed to proper consistency at the paving plant, the proportion of flux to R.A. being recorded in pounds of flux per 100 pounds of R.A. The weight per gallon of bitumen in the A.C. will then vary with the specific gravity and proportion of flux used. Fig. 30 shows the number of pounds of Trinidad R.A. to use in the same mix shown in Fig. 29 for fluxes varying in specific gravity from 0.93 to 1.05 when the number of pounds of flux per 100 pounds of R.A. is known. For various combinations the corresponding number of pounds of R.A. is indicated at the intersection of the diagonal lines with the A.C. curves. As the mineral matter in Trinidad asphalt may be considered as mineral filler, less limestone dust or Portland cement will be required. The exact amount will be governed by the amount of Trinidad R.A. in the mix and this is shown in the lower part of the diagram for R.A. varying from 17 to 27 pounds per square yard.

(*c*) If an oil asphalt or Bermudez R.A. is fluxed at the plant it may be desired to ascertain the specific gravity of the resulting A.C. for use in connection with Fig. 29. This may be calculated, if the specific gravity of both flux and

R.A. are known, by means of the following formula in which x equals the specific gravity of the A.C., a equals the

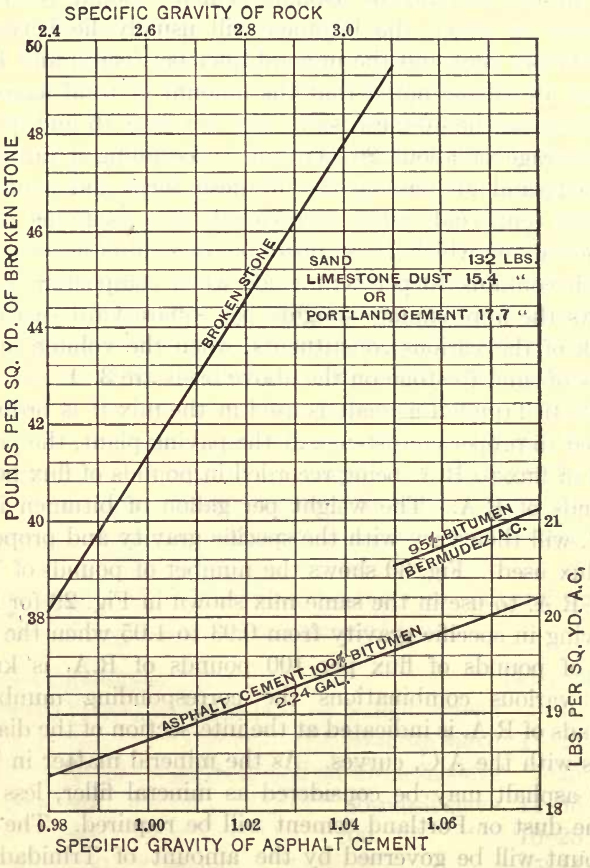

Fig. 29 Quantities of Materials Required for Construction of Fine Graded Aggregate Bituminous Concrete (Topeka Type)

specific gravity of the R.A., b equals the specific gravity of the flux and p equals the number of pounds of flux per 100 pounds of R.A.

$$x = \frac{ab(100 + p)}{100b + ap}.$$

(*d*) These diagrams may be used as described for Fig. 27 (§ 266*b*) for determining weight per square yard and length

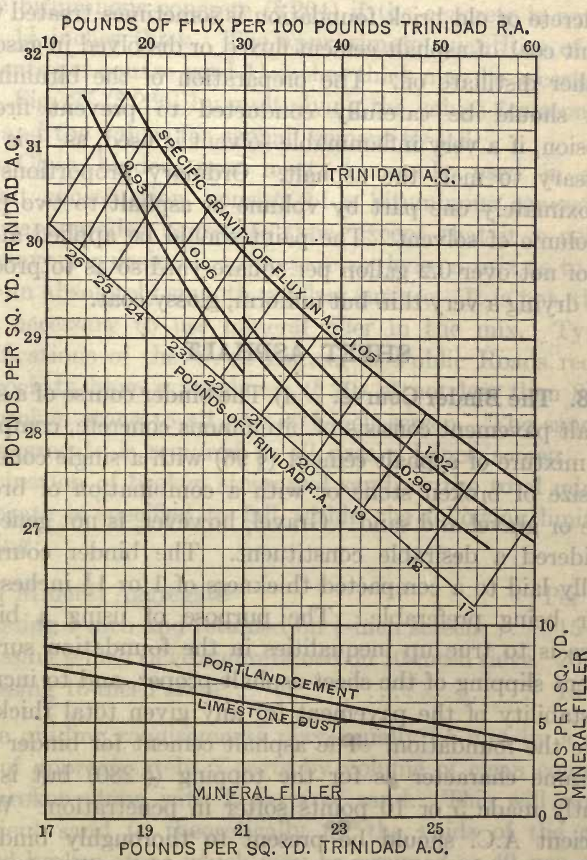

Fig. 30 Quantities of Trinidad A.C. Filler Required for Construction of Fine Graded Aggregate Bituminous Concrete (Topeka Type)

of pavement which should be laid per load of mix of known weight (§ 162). Voids in the compacted mix, as determined from the density of the pavement (§ 384), should not greatly

exceed 4 per cent. If a standard sheet asphalt sand is used the voids may be as low as 2 per cent.

277. Paint Coats. Before laying the mix, the surface of a concrete or old brick foundation is sometimes treated with a paint coat of asphalt cement fluxed or dissolved in gasoline or other distillate oil. The preparation of the bituminous paint should be carefully conducted to prevent fire or explosion, if a very inflammable solvent is used, as it is first necessary to melt the asphalt. Ordinary proportions are approximately one part by volume of asphalt to two parts by volume of solvent. The paint should be applied at the rate of not over 0.2 gallon per square yard so as to produce upon drying a very thin but uniform, glossy coat.

SHEET ASPHALT

278. The Binder Course. (*a*) The binder course of a sheet asphalt pavement consists of bituminous concrete, composed of a mixture of asphalt cement (§ 96) with a single commercial size of broken stone or with a combination of broken stone or gravel and sand. Gravel, however, is not generally considered a desirable constituent. The binder course is usually laid to a compacted thickness of 1 or $1\frac{1}{2}$ inches, the latter being preferable. The purpose of using a binder course is to true up inequalities in the foundation surface, prevent slipping of the sheet asphalt proper, and to increase the stability of the pavement for any given total thickness above the foundation. The asphalt cement for binder is of the same character as for the topping (§ 280) but is frequently made 5 or 10 points softer in penetration. While sufficient A.C. should be present to thoroughly bind the mix, an excess may produce fat spots which will soften the overlying topping. If such fat spots develop during laying they should be cut out and replaced with a suitable mix. For this reason somewhat less A.C. is used in a binder concrete than might be allowed for concrete pavement with the same grading of aggregate.

(b) What is known as open binder is composed of a broken stone aggregate without sand. The quality and grading of the stone may then be the same as described for one-size stone bituminous concrete (§ 264) if the concrete is not less than $1\frac{1}{2}$ inches thick. The approximate quantities of constituents per square yard $1\frac{1}{2}$ inches thick may be ascertained from Fig. 27 (§ 266) by multiplying the values for stone by 0.75 and the values for asphalt cement by 0.6.

(c) Close binder, now most commonly used in sheet asphalt construction, consists of a bituminous concrete of the coarse-graded aggregate type, except that it is neither necessary nor desirable to prepare so dense a mix as to produce an absolutely smooth voidless surface. It is not, therefore, necessary to use mineral filler in the mix. Typical specifications of the U. S. Bureau of Public Roads require the rock to have a toughness (§ 29) of not less than 8 and the broken stone to all pass a 1-inch screen. The sand for fine aggregate is required to all pass a $\frac{1}{4}$-inch screen. The combination of broken stone and sand, or the total mineral aggregate is specified to fall within the following limits of grading:

Total Mineral Aggregate	Per cent
Passing 1-inch and retained on $\frac{1}{2}$-inch screen....	15–65
Passing $\frac{1}{2}$-inch sieve and retained on 10-mesh sieve	20–50
Passing 10-mesh sieve........................	15–35

These grading requirements may usually be met by a mixture of approximately 5 parts by volume of clean commercial broken stone with 2 parts of sand. This will supply sufficient sand to theoretically fill the voids of the compacted broken stone which may be assumed as 40 per cent. The amount of bitumen in the finished mix will then usually run from 4.5 to 6 per cent. Assuming a sand with 40 per cent of voids compacted, Fig. 31 shows the approximate weights per square yard $1\frac{1}{2}$ inches thick of the various constituents.

If Trinidad asphalt is the cementing medium, Fig. 32 should be used to ascertain the number of pounds of asphalt cement required, according to the amount and proportion

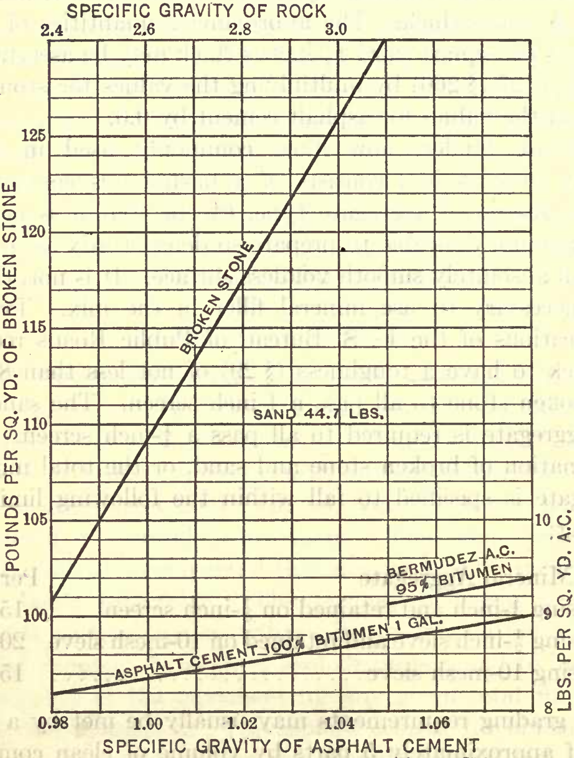

Fig. 31 Quantities of Materials Required for Construction of Binder Course

of flux, as explained in connection with Fig. 30 (§ 276*b*). This diagram also shows the corresponding number of pounds of R.A. for various combinations of R.A. and flux.

279. The Sand Aggregate for Topping. Sand for sheet asphalt topping should be hard, clean grained and moderately sharp. The results of exhaustive investigations,

coupled with many years of practical experience, have led to the adoption of the following two standard gradings, one for light and the other for heavy traffic. An endeavor

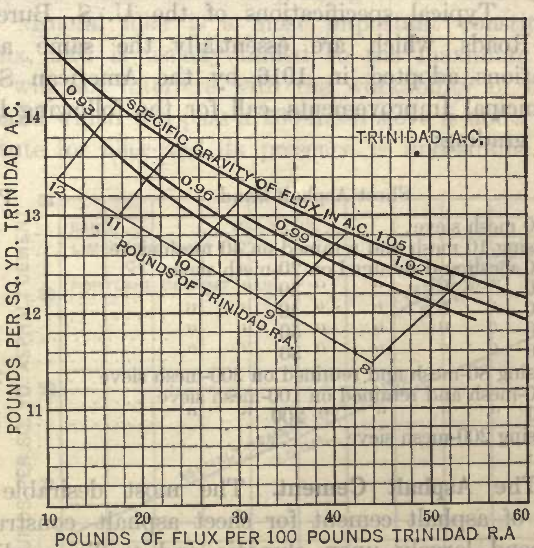

Fig. 32 Quantity of Trinidad Asphalt Required for Construction of Binder Course

is made in actual work to approach one of these two standards as closely as possible, within certain specified limits.

Standard Sand Gradings

	Heavy Traffic Per cent		Light Traffic Per cent	
Passing 10 mesh, retained on 20 mesh sieve	5	23	10	35
" 20 " " " 30 " "	8		10	
" 30 " " " 40 " "	10		15	
" 40 " " " 50 " "	13	43	15	45
" 50 " " " 80 " "	30		30	
" 80 " " " 100 " "	17	34	10	20
" 100 " " " 200 " "	17		10	
" 200 " sieve	0		0	
	100		100	

A single sand will seldom be found to meet such specification limits and recourse must frequently be had to mixtures of two or more sands (§ 249) in order to secure the desired grading. Typical specifications of the U. S. Bureau of Public Roads, which are essentially the same as the specifications adopted in 1916 by the American Society for Municipal Improvements, call for the following limitations of grading:

Sheet Asphalt Sand	Per cent
Passing 10 mesh sieve	100
Total passing 10 mesh and retained on 40 mesh sieve	12–50
Passing 10 mesh and retained on 20-mesh sieve	2–15
" 20 " " " " 30 " "	5–15
" 30 " " " " 40 " "	5–25
" 40 " " " " 50 " "	5–30
" 50 " " " " 80 " "	5–40
Total passing 80-mesh and retained on 200-mesh sieve	20–40
Passing 80-mesh and retained on 100-mesh sieve	6–20
" 100 " " " " 200 " "	10–25
Total passing 200-mesh sieve	0–5

280. The Asphalt Cement. The most desirable consistency of asphalt cement for sheet asphalt construction will depend largely upon climatic and traffic conditions. Typical specifications of the U. S. Bureau of Public Roads require a penetration of from 50 to 60 for northern climates and from 40 to 50 for southern climates or heavy traffic. In addition to oil asphalts, both fluxed Bermudez and Trinidad asphalts are widely used in sheet asphalt construction. With both of the fluxed native asphalts an allowance for non-bituminous impurities (§§ 36*c*, 13) must be made when proportioning the bitumen in the mix. The fine mineral matter in Trinidad asphalt is, in addition, considered as a substitute for filler and this fact should be taken into account in proportioning the filler if fluxed Trinidad asphalt is used. Other physical and chemical requirements commonly included in specifications for the various asphalt cements are shown under Typical Material Requirements (§ 411).

281. The Topping Mix. (*a*) The stability of a sheet asphalt pavement is dependent upon the consistency of the asphalt cement and the grading of the mineral aggregate. Mineral filler is a most important constituent of the mix, and is usually added to the maximum extent, which will not interfere with the workability of the mix. Fine sand which will pass a 200-mesh sieve is not a suitable substitute for filler and its presence is undesirable. Sand

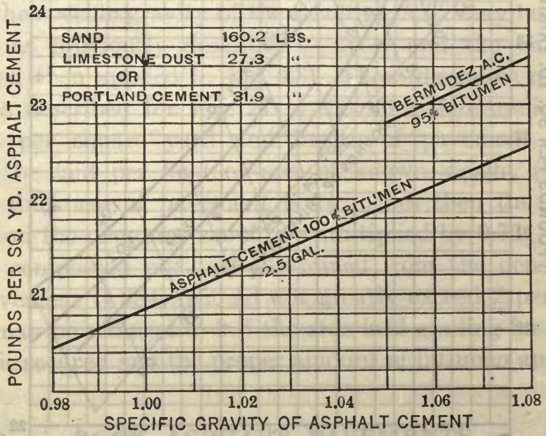

Fig. 33 Quantities of Materials Required for Construction of Sheet Asphalt Surface

passing the 80- and 100-mesh sieves is, however, desirable and the amount of filler which the mix will carry is largely dependent upon the 80- and 100-mesh sand which is present. The presence of a certain amount of relatively coarse grains such as the 10, 20 and 30 mesh particles is highly desirable in order to impart stability to the mix. An excess of such grains, however, will produce a coarse open texture which is unstable when subjected to heavy traffic.

(*b*) The surface mixture or topping, composed of sand meeting the specification requirements previously given (§ 280), will ordinarily carry from 6 to 20 per cent of filler

and from $9\frac{1}{2}$ to $13\frac{1}{2}$ per cent of bitumen. The lower limits are approached in the light traffic mixes and the higher

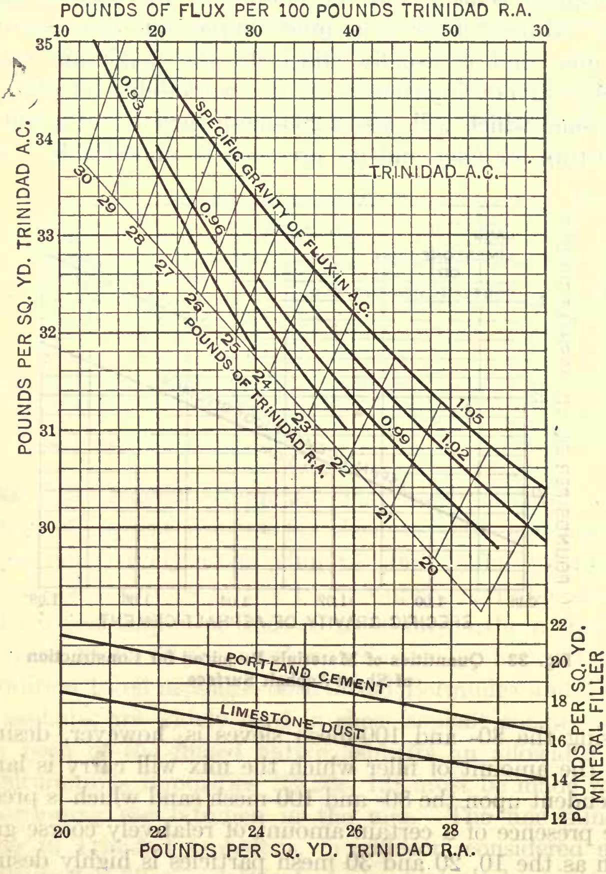

Fig. 34 Quantities of Trinidad Asphalt and Filler Required for Construction of Sheet Asphalt Surface Course

limits in the heavy traffic mixes. For a reasonably well-graded sand which may be assumed to contain 35 per cent of voids when compacted, Fig. 33 shows the approximate weights per square yard, 2 inches thick, of the various con-

stituents of the mix, if an oil asphalt or a fluxed Bermudez asphalt is employed as a binder.

If Trinidad asphalt is used reference should be made to Fig. 34 to ascertain the weight of A.C. and the corresponding weight of R.A. for various combinations of the asphalt with fluxes of different specific gravity (§ 276*b*). From the weight of R.A. that of the corresponding amount of filler needed is shown in the lower part of the diagram.

(*c*) If an oil asphalt or Bermudez R.A. is fluxed at the plant the specific gravity of the resulting A.C. may be ascertained as previously described (§ 276*c*) and the value so obtained then applied to Fig. 33. These diagrams may be used as described for Fig. 27 (§ 266*b*) for determining the weight per square yard and length of pavement which should be laid per load of mix of known weight (§ 162). If the thickness of pavement is $1\frac{1}{2}$ inches then the values shown on the diagrams should be multiplied by 0.75. Voids in the compacted mix, as determined from the density of the pavement (§ 384), should not greatly exceed 2 per cent. They may be reduced to 0 if the standard grading for heavy traffic is secured and the proper amount of bitumen and filler used.

ROCK ASPHALT PAVEMENTS

282. Bituminous Sandstone. Natural bituminous sandstones (§ 100), after crushing and sometimes heating in a revolving drum, have been used to a limited extent in the construction of sheet pavements. Such pavements, in general, resemble artificial sheet asphalt but, owing to variations in the natural product, are apt to be less uniform and to possess a less desirable sand grading. Specifications for bituminous sandstones usually covered the grading limitations of the mineral aggregate and the per cent of bitumen which must be present. Samples should, therefore, be taken from each shipment and no sample should represent more than 50 tons. These samples should be sub-

jected to laboratory examination before the material is used. Sometimes specification requirements can only be met by an admixture of two or more grades of rock asphalt or by the addition of flux or asphalt cement, in which case plant inspection may involve determinations of the per cent of bitumen in the product (§ 133), in addition to grading tests of the extracted mineral aggregate. The same general considerations governing sheet asphalt construction should apply to pavements constructed of rock asphalt of the bituminous sandstone type.

283. Bituminous Limestone. Bituminous limestones (§ 100) are usually crushed down to the state of fine powder before being used in the construction of the sheet type of pavement. In such products grading of the mineral matter does not appear to be a matter of moment as each fine particle is impregnated with asphalt and coalesces with its neighboring particles, under compaction, to produce a dense tough mastic highly resistant to displacement under traffic. The powder is heated in a revolving drum or open pan to a temperature of approximately 300° F. after which it is spread and compacted as in sheet asphalt construction. Hand tamping is, in addition, highly desirable in order to secure maximum compaction. As in the case of bituminous sandstone, it may be necessary to combine two or more grades of the rock asphalt or to add flux or asphalt in order to secure a uniform product. Specification requirements for this type usually call for the presence of from 9 to 12 per cent of bitumen. This can only be ascertained by means of a laboratory test (§ 133). A sample should, therefore, be taken for each 50 tons of product and subjected to laboratory test before the material is used.

BITUMINOUS EARTH PAVEMENTS

284. The Mineral Aggregate. Pavements constructed of a mixture of earth and asphalt cement have barely passed

the experimental stage, so that information relative to the best type of earth for the mix is limited. In general, however, it appears that the finer the state of subdivision the better. A pure clay should, therefore, prove to be the best type. Such a product thoroughly mixed or impregnated with asphalt appears to possess properties similar to the finely crushed natural bituminous limestones (§ 283) in which the exact grading of the mineral parcticles does not seem to be of great importance. Before admixture with the asphalt, all clumps of mineral particles should be broken up and, in the National Pavement, which is patented, this is accomplished by passing the earth through a heating drum equipped with a special disintegrating device. Specifications for this pavement require the pulverized earth to conform to the following limitations:

	Per Cent
Passing 20-mesh and retained on 50-mesh sieve...	0–20
" 50- " " " " 200- " " ...	0–30
" 200- " sieve........................	50–100

In addition, the earth is required to develop a tensile strength of not less than 50 pounds per square inch when mixed to a stiff paste with water, molded in a cement briquette mold (§ 81) and allowed to dry. Upon ignition at a red heat it is required to lose from 3 to 12 per cent. It is further required to be soluble in dilute 1 : 2 hydrochloric acid to the extent of from 5 to 15 per cent but to contain not more than 5 per cent of carbonates. The value of specifying such properties, which can only be determined by laboratory test, is still a matter of speculation, due to the limited amount of service data which is available.

285. The Asphalt Cement. The consistency of asphalt cement used in bituminous earth mixtures is much softer than for sheet asphalt and in fact is the same or nearly the same as for bituminous macadam. Specifications for the National Pavement call for an asphalt cement of from 80 to 150 penetration, depending upon the fineness of the pul-

verized earth, traffic and local climatic conditions. Best results, so far obtained, appear to have been secured with an asphalt cement of about 90 penetration in combination with a soil, 80 per cent of which would pass the 200-mesh sieve.

286. The Mix. Specifications for the National Pavement require the mix to contain from 15 to 20 per cent of bitumen. Within these limits the finer the texture of the soil the more bitumen will be required. The weight per square yard for asphalt earth mixtures 2 inches thick compacted will vary with the specific gravity and proportion of the constituents, as in the case of other mixtures, but will approximate 180 pounds. Upon the basis of 17 per cent of bitumen this will represent 30.6 pounds of asphalt cement and 149.4 pounds of dry soil per square yard.

MAINTENANCE

287. Methods. (*a*) Ordinary maintenance of bituminous concrete pavements, originally constructed with a seal coat, involves surface treatment with bituminous material and cover exactly as described for bituminous macadam (§ 206*a*). Holes and depressions for all types should be remedied by cutting out the pavement so as to produce excavations with approximately vertical sides for the entire thickness of wearing course. The excavation should then be thoroughly cleaned and filled with a hot bituminous mixture of the same kind as used in original construction, which should be thoroughly tamped to produce smooth even joints with the surrounding area. For the coarse aggregate type of pavement, patches are occasionally made with a mixture of broken stone and emulsified asphalt or cut-back tar (§§ 333, 334).

(*b*) Cracks, in bituminous concrete pavements containing relatively large fragments of broken stone, are of less common occurrence than in pavements of the sheet type. In

the latter they are sometimes due to contraction cracks formed in the underlying concrete foundation and sometimes to the use of too little or too hard a bitumen in the mix. They are difficult to repair satisfactorily and, in general, had better be left alone until the edges begin to disintegrate and wear away. A patch may then be made by cutting out the pavement on both sides of the crack and filling with fresh mix. The sides of the hole are sometimes lightly painted with hot bituminous cement before the new mix is tamped into place. Great care should be exercised to obtain a well-bonded joint or two cracks, one on each side of the patch, are likely to develop in place of the one original crack.

(*c*) General waviness is usually due to an unstable foundation, the presence of a poorly graded aggregate, or to the use of too much or too soft a bituminous cement. This condition is practically impossible to remedy without reconstructing or resurfacing the pavement. Failures due to foundation causes should be remedied by removal and replacement of the foundation wherever repairs are required in the pavement proper.

(*d*) In the sheet types of pavement, maintenance by resurfacing is sometimes accomplished by means of the surface heater method. The surface heater consists of an apparatus for bringing hot air or superheated steam into contact with the pavement until the old mix has been softened to the desired depth. All burned material is then removed from the heated area and immediately replaced with fresh hot mix which is spread and compacted as in original construction. Such method of repairing should, of course, be limited to cases involving failure of the wearing course only, in which disintegration has progressed from the top down and not from the bottom up.

288. Inspection. Inspection of maintenance by seal coating will usually be the same as for surface treatment (Chapter IX). For patching it will be the same as for original

construction and may involve both plant and street inspection depending upon the extent of repairs and the quantities of materials used.

INSPECTOR'S EQUIPMENT

289. Construction. For construction work involving the use of small portable paving plants, the street Inspector may also be required to act as plant Inspector, in which case he will require certain equipment listed under the Plant Laboratory (§ 253), in addition to that needed on the street. Ordinarily, however, where both plant and street Inspectors are employed the latter will find the following sufficient for his work.

For Measurements:
- A 50-foot steel tape.
- A pocket rule (§ 387).
- A stout screw driver or 2-inch putty knife.

For Sampling:
- A supply of tin or wooden boxes for holding samples of the mix. (An ordinary cigar box is sufficiently large for all but very coarse aggregate with fragments greater than 1 inch in diameter.)
- A supply of gum labels for identification information.
- A few very stout boxes may be required occasionally for packing samples of compressed pavement about 1 foot square.
- A supply of 1 quart tin cans for seal coat or paint coat materials.

For Testing:
- An armored thermometer (§ 386).
- [1] Two field screens (§ 371) as may be called for by specifications for seal coat cover.

[1] Ordinarily this apparatus may be dispensed with, provided samples of seal coat cover are taken by the street Inspector and tested by the plant Inspector before use.

[1] A spring balance with pan capacity of 10 pounds if seal coat cover is to be tested (§ 371).

For Records and Reports:

A field diary and pencil.

A supply of report forms (§ 404).

A carbon paper for duplication of reports.

290. Maintenance. For maintenance the street Inspector's equipment may be the same as for surface treatment with carpeting mediums (§ 191) or it may be as complete as that required for original construction, depending upon the character and volume of work. If extensive repairs to concrete foundation are involved, additional equipment listed under construction of concrete pavements (§ 233) may be required.

[1] *Ibid.*

CHAPTER XIV

INSPECTION OF BRICK AND BLOCK PAVEMENTS

GENERAL CHARACTERISTICS

291. Types of Pavements. (*a*) Brick and block pavements are most commonly classified according to the material of which they are composed. These are:

Vitrified shale or clay.
Slag.
Stone.
Bituminous Concrete (commonly known as asphalt block).
Creosoted Wood.

During manufacture the material is molded or cut into approximately rectangular shapes of the same size and dimensions and the pavement proper is usually laid in regular courses so as to break joints between the courses. An exception to this method is found in the use of small, irregular, but approximately cubical stone block, known as irregular sets, which are laid in circular arcs.

(*b*) Brick and block are sometimes laid upon a cushion or bed of sand resting upon the foundation and sometimes upon a mixture of sand and Portland cement. In addition to the name of the material proper, such pavements are known as sand cushion or mortar cushion pavements. When brick, stone or slag blocks are laid directly upon a green concrete foundation so as to be held in place by the concrete as it sets, the pavement is commonly termed mono-

lithic. When a concrete foundation has already set but the brick or block are bonded to it by the use of a cement-sand or mortar cushion, the pavement is said to be semi-monolithic. In both the monolithic and semi-monolithic types a cement mortar grout is used to fill joints between the brick or block.

(*c*) Brick and block pavements are also frequently described by the material used in filling joints. This may be cement mortar grout, poured asphalt or tar pitch, or a bituminous grout composed of a mixture of bituminous material and sand. Less frequently sand or fine gravel only are used to fill joints.

292. General Methods of Construction. Unless a green concrete foundation is used, the foundation is first covered with a cushion or bed of sand, or sand and cement, to true up surface inequalities and provide an adjustable setting which will permit the top surfaces of the block to be brought flush with one another under compaction. The blocks are then laid by hand upon this bed in straight courses, at right angles to the center line of the pavement so as to break joints between adjacent courses. If a joint filler is to be used lugs or projections on one side and end of the block serve to produce uniform spacing. After the blocks have been laid the pavement is rolled to true up the surface and bring every block to a firm bedding. If a joint filler is needed it is then poured or broomed into the joints between the blocks so as to completely fill them from the bottom up. The pavement may then be opened to traffic except in the case of a cement grout filler which requires protection for a period of not less than 7 days.

DETAILS OF CONSTRUCTION APPLICABLE TO ALL TYPES

293. Foundations. While in some instances brick and block pavements have been laid upon broken stone, slag or

gravel foundations, and even upon the natural soil with the use of a sand cushion, it is generally conceded that a cement concrete foundation (§ 219) is the most suitable type. The construction of a concrete foundation for such pavements is the same as for any other, the only modification being that of the monolithic brick pavement. In this type great care should be exercised in making the concrete of uniform consistency, and the foundation surface as true and smooth as possible. As the foundation construction is then immediately followed by laying and rolling the brick, it is essential that it be kept no further in advance of the brick laying than will be required to firmly bed the brick before initial set has occurred.

294. Cushions or Beds. (*a*) When a plain sand cushion is used, it is spread over the clean foundation so as to produce the compacted depth which is specified, usually 1, $1\frac{1}{2}$ or 2 inches. The sand should all pass a $\frac{1}{4}$-inch screen and should contain not over 5 per cent removed by the elutriation test. At least one sample from each shipment of sand (§ 60) should be taken and tested before use. The cushion should be shaped to the desired cross section by means of a template and then rolled with a hand roller, weighing not less than 10 pounds per inch width of tread and provided with a handle not less than 12 feet long. During rolling the sand should be slightly moist and a light sprinkling with water may be necessary. After initial compaction, the cushion should be reshaped and rerolled until firm and true to the required cross section. It should be prepared about 50 feet in advance of the brick or block laying and should not be walked upon or disturbed after final shaping. If displaced by any cause it should be carefully reshaped and compacted before the brick are placed.

(*b*) Cement-sand beds are composed of a dry mixture or cement and sand in specified proportions, usually 1 : 3 or 1 : 4. The mix is preferably prepared in a mechanical batch mixer and should be of uniform quality and color.

It is spread upon the clean foundation to produce the specified compacted depth, usually ½ or 1 inch. It is then shaped and rolled as described for sand cushion, without

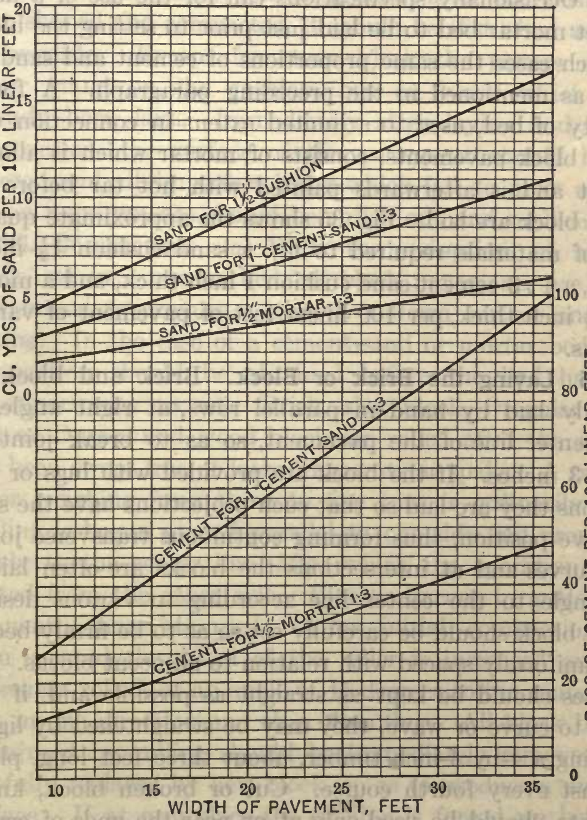

Fig. 35 Quantities of Materials Required for Construction of Cushions

the use of water. The bed is later set by a sprinkling of water after the blocks have been laid. Sometimes, however, the bed is sprinkled just before they are laid. No more of this type of bed should be laid in advance than can be covered during the working period The sand should

all pass a $\frac{1}{4}$-inch screen and show not more than 5 per cent removed by the elutriation test (§ 53*b*). At least one sample of sand and cement should be taken and tested before use.

(*c*) Occasionally specifications call for the use of a damp or wet mortar bed to be laid just prior to setting the block. In such cases the same proportions of cement and sand are used as mentioned in the preceding paragraph. A fourth variety of bed, used to a limited extent in connection with wood block pavements, consists of mortar which is allowed to set and is afterwards painted with hot tar before the wood block are laid. Fig. 35 shows the approximate quantities of materials required to lay a sand cushion $1\frac{1}{2}$ inches thick, a 1 : 3 cement-sand cushion 1 inch thick, and a mortar bed $\frac{1}{2}$ inch thick, per 100 linear feet of pavement of various widths.

295. Laying the Brick or Block. Brick and block are usually laid by hand in parallel rows, at right angles to the center line of the pavement, so as to break joints at least 3 inches. If the block are provided with lugs or projections they are laid so that such projections have the same relative position, thus forming continuous transverse joints. On curves and at intersections the blocks are often laid at an angle to the center line according to various designs. Each block should be carefully set so as to be firmly bedded and uniformly spaced with relation to adjacent blocks. The courses should be kept as straight as possible and, if they tend to curve or wave, they may be straightened by lightly striking a 4-by 4-inch timber, about three feet long, placed against every fourth course. Cut or broken block, known as bats, should be used only at or near the ends of courses to fill in spaces too small to hold full size block. Bats should have clean sharp edges so formed as to produce neat joints with the surrounding blocks. If a joint filler is to be used, all spaces between the blocks should be kept open and clean from the bottom up until the filler is applied. With block, which vary materially in depth, considerable skill is re-

quired to bed them so that a surface, true to crown and grade, will be obtained after compaction. This may at times require slight adjustment in the thickness of cushion under individual block but, in general, after the cushion is once shaped and compacted, it should be disturbed as little as possible. Except for stone block the pavers should never stand on the cushion, but on block which have already been laid. Immediately after laying and before compaction, the surface of the pavement should be inspected and all imperfect block which fail to meet specification requirements should be culled out and replaced.

296. Compaction. (*a*) With the exception of asphalt block, set in a mortar bed, all block pavements are rolled or rammed to produce a smooth uniform surface and firm setting. In the case of a cement-sand or mortar bed, final compaction should be obtained before the bed has had an opportunity to set. Brick, slag block, irregular stone sets or Durax, and wood block are rolled after the surface has been swept free of loose fragments or spalls. A tandem roller weighing from three to five tons is ordinarily used. Rolling is begun at and parallel to one side and progresses slowly to the center line, after which the operation is repeated from the other side. Block adjacent to gutters are frequently hand tamped. After initial compaction has been secured the speed of the roller is increased and the pavement rolled, at an angle of 45 degrees to the center line, first in one direction and then the other. All block broken or injured by rolling should be immediately removed and carefully replaced by new block, so as to produce a uniform surface. If at any place the cushion is forced up between the block, for a depth of over $\frac{1}{2}$ inch, the block should be removed and relaid after reshaping and compacting the cushion.

(*b*) In regular stone block paving, each individual block should be rammed to a firm even bed by striking the block squarely in the center of its surface. The rammers usually

weigh between 35 and 50 pounds. After ramming, blocks which have been forced below the finished grade should be removed with tongs so as not to disturb the bedding or position of adjacent block. They are then relaid with the addition of cushion material, and rammed. Pinch bars should not be used to remove block. Ordinarily, stone block should be rammed soon after laying and not more than 25 feet behind the laying.

297. Joint Filling. (*a*) Plain sand filler is at present almost exclusively limited to asphalt block pavements, which are laid with as close joints as possible. In such pavements, as soon as the block are laid they should be covered with fine, dry, clean sand which will pass a 10-mesh sieve. The sand should be swept into the joints and an excess allowed to remain on the surface of the pavement until traffic has completely filled or closed the joints.

(*b*) Cement grout filler for brick, slag block and stone block pavements is composed of equal parts by volume of cement and sand mixed, preferably in a batch mixer, with water to a thin creamy consistency which will permit it to flow readily into the joints and fill them from the bottom up, but not so thin that the sand and cement will separate. To prevent such separation the grout should be constantly agitated until it is flooded over the pavement which is first sprinkled with water. It is then broomed into the joints until flush with the surface. As the grout shrinks additional grout is broomed in until the joints will take no more, after which, all excess is squeegeed off of the pavement. Metal strips $\frac{1}{16}$ of an inch thick, 6 inches wide and not less than 3 feet long should be inserted between the blocks, across the pavement to close a stretch of grouting, with a straight joint at the end of each working period. As soon as the grout has reached its initial set, the pavement should be covered with $\frac{1}{2}$ inch or more of clean sand. It should then be sprinkled two or three times a day to prevent the grout from drying out too rapidly. At the end of a week or ten

days the sand covering may be removed. Grouting sand should consist of clean hard quartz grains. Typical specifications of the U. S. Bureau of Public Roads require it to meet the following grading limitations:

	Per cent
Passing 10-mesh sieve..................	100
" 20- " " , not less than......	80
" 100- " " " more than.....	10

These specifications further require that it show not more than 5 per cent removed by the elutriation test (§ 53*b*) and that it develop a mortar tensile strength (§ 58) of at least 75 per cent of that developed by standard mortar. At least one sample of grouting sand should be taken from each shipment and tested before use. Cement should meet the usual standard specifications (§§ 65–67), and each shipment should be sampled and tested.

(*c*) Hot poured bituminous fillers may be used for all types of brick and block with the exception of asphalt block. For brick, slag block and stone block, an asphalt filler of the blown type (§ 97) is most commonly used. Typical specifications of the U. S. Bureau of Public Roads require that such a filler show a melting point, by the ring and ball method (§ 126), of not less than 80° C. and a penetration (§ 125) at 25° C. of from 30 to 50. The penetration at 0° C. is specified at not less than 20, and at 46° C. at not more than 100. For wood block pavements, a tar pitch filler (§ 104) is most commonly used. The 1916 specifications of the American Society for Municipal Improvements require that such a filler show a melting point, cube method in water, of from 60° to 66° C. and that it contain from 22 to 37 per cent of free carbon (§ 133). Other physical and chemical properties of asphalt and tar fillers commonly specified are given under Typical Material Requirements (§§ 411, 413). The general method of applying hot poured bituminous fillers is the same as for expansion joints (§§ 328,

329) except that sometimes an excess of filler is used to flood the surface and upon squeegeeing to produce, with the later application of mineral cover (§ 184), a bituminous mat or carpet (§ 178) over the entire pavement. At least one sample of bituminous filler and cover should be taken from each shipment and tested before use.

(*d*) Bituminous grout or mastic fillers are sometimes used for filling joints in stone block and brick pavements. Such mastic is prepared by mixing hot sand and bituminous material in such proportions as to produce a thin grout which, at the temperature of application, is sufficiently fluid to flow into the joints and completely fill them. The mixture is made up by hand in small batches in steel wheel barrows and will ordinarily carry from 40 to 60 per cent by volume of bituminous material. The sand should be of the same grade and quality as for cement grout (§ 297*b*). For use with tar it should be heated to between 250 and 325° F. and with asphalt to between 325 and 400° F. For tar pitch the 1916 specifications of the American Society for Municipal Improvements require a melting point, cube in water method, of from 46° to 57° F. and from 20 to 35 per cent of free carbon (§ 133). For asphalt a melting point (§ 126) of from 54° to 63° C. is required and a penetration (§ 125) at 25° C. of from 60 to 100. Other physical and chemical properties commonly specified for both tar and asphalt are given under Typical Material Requirements (§ 413). Whichever bituminous material is used, the temperature to which it is heated should lie between the temperature limits given for sand. Immediately after mixing, the bituminous grout should be flooded upon the pavement surface and squeegeed into the joints before it has had an opportunity to harden. Great care should be exercised to fill all joints from the bottom up. As little excess grout as possible should be left on the surface of the pavement and whatever remains should be covered with a light coat of the hot sand. At least one sample of bituminous material and

sand should be taken from each shipment and tested before use.

298. Expansion Joints. Expansion joints for cement grouted pavements are commonly placed along curbs or gutters and sometimes extend through the entire thickness of pavement and concrete foundation. Transverse expansion joints are also sometimes inserted, particularly at street intersections. Bituminous fillers are specified for filling expansion joints and the application and properties of such fillers are described later (§§ 328–330).

299. Hillside Construction. In order to reduce slipperiness on heavy grades, special forms of block and brick are often used. Such block may have one long edge on the upper face beveled, or the upper face may be corrugated, grooved or ridged. After filling joints between such block, the filler is broomed out of the depressions, joints or grooves for a sufficient depth to insure foothold for horses.

300. Measurement. Brick and block pavements are commonly measured and paid for upon a square yard basis, complete in place, including brick or block, cushion, filler and expansion joints. Sometimes, however, bituminous materials are paid for as a separate item, in which case the Inspector, in addition to measurements of length, width and depth of pavement and blocks, should keep track of the amount of bituminous material used. He should also keep track of the actual and relative volumes of all constituents of grout fillers and mortar cushions or beds. Under the various types of brick and block in the following paragraphs, diagrams are given which may be of service in the matter of measurement.

VITRIFIED SHALE AND CLAY BRICK

301. Types of Brick. (*a*) Paving brick are manufactured either from fire-clay or an intimate mixture of shale and fire-clay. The latter are known as shale brick and are

usually dark brown or red in color, while the fire-clay brick are buff or yellow. The raw material, after proper reduction or grinding, is mixed with water to produce a thick slurry or paste which is forced through dies or formers and emerges as an approximately rectangular column or ribbon. The individual brick are formed by cutting off sections of the ribbon to the desired thickness. The green brick are then allowed to dry, after which they are stacked in kilns and burned to incipient vitrification. They are then slowly cooled or annealed. The manufacturing process requires careful selection of materials, and control of details, in order to produce brick which are hard, regular in shape and free from undesirable checks, cracks and kiln marks. There are three main types of paving brick, which are classified according to certain details of manufacture, as repressed brick, wire-cut lug brick and vertical fiber brick.

(*b*) Repressed brick are made by repressing the green brick in suitable molds before they are burned. Under repressing, lugs may be formed and the edges rounded. Sometimes raised letters or trade marks which serve as lugs are formed by the molds, and sometimes the letters are depressed.

(*c*) Wire-cut lug brick are formed by cutting the clay ribbon, by a patented process, so as to produce lugs on one of the cut surfaces of the brick. The cut surfaces, which are sometimes rough and porous, then form the sides of the brick, as laid, while the wearing surface has the smooth dense finish left by the mold.

(*d*) In the manufacture of vertical fiber brick, the ribbon of clay is cut straight through and the lugs, if made, are formed by the die through which the clay is forced. The wearing surface of such brick will then be one of the cut faces. Because the upper surface somewhat resembles the rough cross-cut section of a compact bundle of fibers, the name vertical fiber has been given to this type of brick.

302. Rattler Test. (*a*) The only test limit commonly specified for paving brick is the percentage of loss by abrasion when subjected to the rattler test. This test has been standardized by the American Society for Testing Materials as Standard Test C7–15. Briefly described, the standard rattler consists of a steel barrel made up of two solid heads with staves spaced $\frac{5}{16}$ inch apart. This barrel is made to revolve about a horizontal axis at a standard rate of speed. The abrasive charge consists of 10 cast-iron spheres, weighing $7\frac{1}{2}$ pounds each, and a sufficient number of smaller spheres, weighing 0.95 pound each, to bring the total weight of charge to as near 300 pounds as possible. The brick charge consists of 10 thoroughly dried brick, none of which would be rejected upon visual inspection and which are carefully weighed. The test consists in subjecting the brick to 1800 revolutions of the rattler, at the end of which time they are reweighed, rejecting any fragment weighing less than 1 pound. The loss in weight is calculated as percentage of the original weight and test results are expressed as per cent of wear. Sometimes each individual brick is marked for identification by drilled holes, weighed separately, and its individual per cent of wear determined.

(*b*) Specifications covering per cent loss by abrasion of the brick, when subjected to the rattler test, vary considerably. Sometimes the maximum loss of the entire charge only is specified and sometimes both maximum and minimum loss of individual brick are covered. Occasionally the loss of different grades of brick obtained from different degrees of burning, as ascertained by visual inspection, is covered in specification requirements. Sampling brick for the rattler test (§ 306) is a matter which may require considerable judgment on the part of the Inspector, depending upon specification requirements. Typical specifications of the U. S. Bureau of Public Roads for brick of 4-inch and 3-inch depth include the following requirements in connection with the rattler test:

Rattler loss	4″ Brick	3″ Brick
Average loss on one or more rattler charges, not more than	22%	26%
Maximum loss by any one charge when two or more samples are tested	24%	28%
Maximum difference in per cent of loss between any two charges	8	8

It is further specified that a maximum of three tests may be used as a basis for rejection.

303. Size. Although there are exceptions, the size of paving brick or block has been fairly well standardized within reasonably narrow limits. The average length is $8\frac{1}{2}$ inches and width $3\frac{1}{2}$ inches. Two depths are used, 4 inches and 3 inches. Four-inch brick weigh approximately 10,000 pounds per thousand and three-inch brick about 7,500 pounds per thousand. The weight of different makes of brick of a given size may vary considerably, however, as their specific gravity varies from 1.9 to 2.7 with an average of a little over 2.3. Variation in the width and depth of individual brick from a single plant or for a given job is usually specified at not over $\frac{1}{8}$ inch and variations in length at not over $\frac{1}{2}$ inch. In addition to such limitations, typical specifications of the U. S. Bureau of Public Roads require brick to meet the following dimension limitations:

Dimensions	4″ Brick	3″ Brick
Length in inches	$8\frac{1}{4}$–$9\frac{1}{4}$	8–9
Width in inches	$3\frac{1}{4}$–$3\frac{3}{4}$	$3\frac{1}{2}$–4
Depth in inches	$3\frac{7}{8}$–$4\frac{1}{8}$	$2\frac{7}{8}$–$3\frac{1}{8}$

304. Joints. With lug brick averaging $8\frac{1}{2}$ inches in length and $3\frac{1}{2}$ inches in width, 40 will be required per square yard. The joint spaces will then be approximately $\frac{1}{4}$ inch in width and will amount to 106 square inches to the square

yard, or about 8 per cent of the total area. The joint volume for a 4-inch brick pavement will then approximate

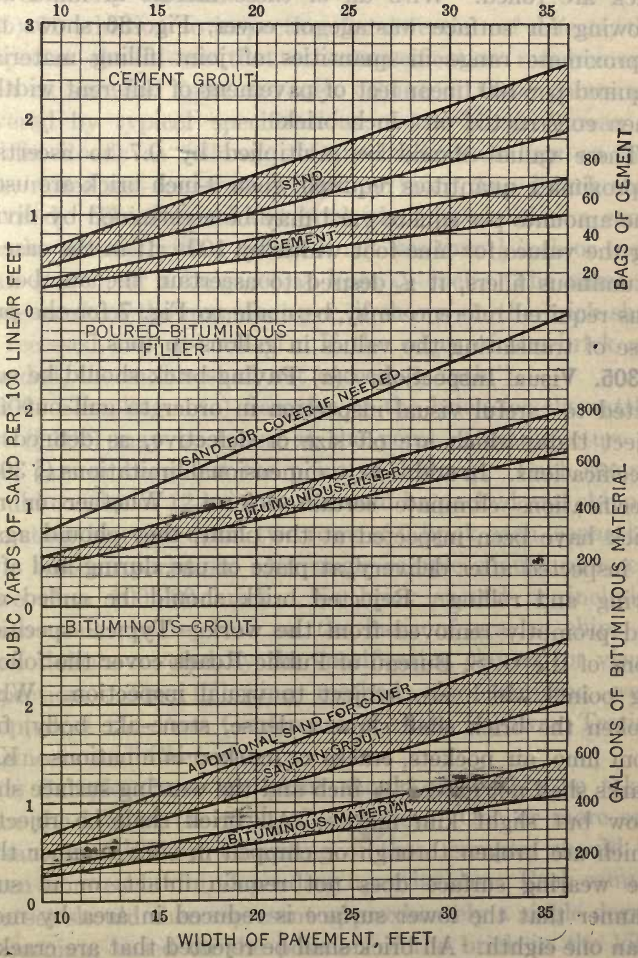

Fig. 36 Quantities of Materials Required for Filling Joints in Brick Pavements

424 cubic inches and for a 3-inch pavement 318 cubic inches. This volume may be reduced from 6 to 12 per cent, for 4-

inch brick, and from 8 to 16 per cent for 3-inch brick, by cushion material being forced up into the joints when the brick are rolled. With all of these factors in mind and allowing for surface wastage or cover, Fig. 36 shows the approximate range in quantities of joint filling materials required per 100 linear feet of pavement of different widths, when constructed of 4-inch brick.

These values should be multiplied by 0.7 to ascertain approximate quantities required when 3-inch brick are used. The amounts per square yard may be ascertained by dividing the values for nine-foot width by 100. If in the case of bituminous fillers, it is desired to ascertain the number of tons required reference may be made to Fig. 7 for the purpose of translating the values in gallons to tons.

305. Visual Inspection. (*a*) Paving brick should be subjected to careful visual inspection in order to cull out and reject those which are off size or defective, as defined by specifications. In addition to dimensional limitations (§ 303), specifications eliminate certain defects. Whether or not brick have been inspected at the plant, they should again be inspected after delivery, at place of use, during and after laying and rolling. Rejected brick should be culled out and promptly removed from the work. Typical specifications of the U. S. Bureau of Public Roads cover the following points which are subject to visual inspection. When broken the brick shall show a dense, stone-like body, free from lime, air pockets, cracks or marked laminations. Kiln marks shall not exceed $\frac{3}{16}$ inch and the wearing surface shall show but slight kiln marks. All brick shall be rejected which are broken through or chipped in such manner that the wearing surface does not remain intact, or in such manner that the lower surface is reduced in area by more than one eighth. All brick shall be rejected that are cracked to a depth greater than $\frac{1}{8}$ inch on any surface, or that are cracked on the wearing surface. All brick shall be rejected that are so misshaped, bent, twisted, or kiln marked that

they will not form a proper surface or align properly with other brick. All brick shall be rejected that are obviously soft or poorly vitrified.

(*b*) In addition to inspecting for detection of defects, the Inspector should see that other specification requirements such as size and form are met. Some of these points are covered by typical specifications of the U. S. Bureau of Public Roads as follows: "Only brick with lugs on one side, raised not less than $\frac{1}{8}$ inch nor more than $\frac{1}{4}$ inch shall be used. The ends of the brick shall have either a semi-circular groove, with a radius of not less than $\frac{1}{8}$ inch or more than $\frac{1}{4}$ inch, or a bulge of at least $\frac{1}{16}$ inch. The name or trade mark of the manufacturer, if shown on the brick shall be recessed and not raised. If the edges of the brick are rounded, the radius shall not exceed $\frac{3}{16}$ inch."

306. Sampling. (*a*) Samples of the brick for the rattler test (§ 302) may be taken at the point of manufacture or from cars or barges at the point of delivery. Each sample should consist of 12 brick and should be packed and shipped in a stout box put up in two rows of 6 brick each, separated by a wooden partition. No single sample should represent more than 100,000 brick. No brick should be included which would be rejected on the basis of cracks, chips or other defects covered by the specification clauses for visual inspection. The following methods for sampling were adopted at the First Conference of State Highway Testing Engineers and Chemists.

(*b*) Samples from the plant should preferably be taken from the kiln at the time of emptying. One or more sets of samples, each set consisting of three samples should be taken from each kiln, depending upon its size. Each sample in a set should then represent approximately a single degree of burning, based on the position of the brick in the kiln. Samples taken from piles at the plant should represent as nearly as possible the entire run of the brick. Samples should be taken from as many different points, correspond-

ing to the length, breadth and depth of the pile as possible. In no case should samples be confined to the upper or outer few layers. Where controversy arises regarding the admissibility of certain types or portions of the lot, entire test samples may be selected from such types or portions having a characteristic appearance in common.

(*c*) When sampled at the point of delivery a representative sample should be taken from each carload received. Considerations covered under sampling from piles at the plant apply equally to sampling from cars.

SLAG BLOCK

307. Manufacture. Slag block, commonly known as scoria block, are manufactured from blast furnace slag (§ 168*b*) by running the molten slag into rectangular molds where they are allowed to slowly cool and harden. At the present time few, if any, slag block are manufactured in this country and when used here they are usually imported from England.

308. Properties. Slag block are of approximately the same size as paving brick with the edges on the upper face slightly beveled. The imported variety are hard and dense and have a higher specific gravity than brick. They are highly resistant to the destructive action of heavy traffic and have been successfully used for paving between street car tracks, to which purpose their use in this country has been generally limited.

STONE BLOCK

309. Types of Block. Stone block for paving purposes are usually manufactured from granite (§ 21) or sandstone (§ 23) although trap (§ 20) and limestone (§ 22) have been used to a very limited extent. The ordinary size of block are cut or split by hand from dimension stone or larger rectangular blocks which have been carefully quarried. For this

purpose the rock must split readily along two planes at right angles to each other. Small cubical block known as irregular sets and marketed under the name of "Durax" are cut from granite by a machine instead of by hand.

310. Tests. No absolutely satisfactory set of tests for stone block has as yet been devised and at present specification requirements for physical properties cover only resistance to abrasion (§ 28) and toughness (§ 29) as determined upon rock used in the manufacture of broken stone. At one time a minimum crushing strength was commonly specified but it is now generally conceded that this test is of no practical value in connection with paving block. The 1916 specifications of the American Society for Municipal Improvements require for granite block, for heavy traffic, a minimum toughness of 9 and a minimum French coefficient of wear of 11. For medium traffic a minimum toughness of 7 and a minimum French coefficient of wear of 8 are specified.

311. Size. (*a*) Stone block may be obtained in rectangular shapes of any desired dimensions. Three sizes only of granite block are, however, ordinarily manufactured, the dimension limits of each size being shown in the following table. Of these the 5-inch standard size is the one most commonly used. Specifications for length and width-usually mention the top surface only, but they frequently require that the block shall be so dressed that when laid as specified, measurement of any joint shall show a width of not more than $\frac{1}{2}$ inch for a depth of 1 inch, or a width of not more than 1 inch in any part of the joint. The wearing surface of the blocks may furthermore be required to show no depressions

Dimensions	5-Inch Standard	4-Inch Standard	Resurfacing
Length in inches.	8 –12	7–11	7 –11
Width in inches.	$3\frac{1}{2}$–$4\frac{1}{2}$	4–$4\frac{1}{2}$	$3\frac{3}{4}$–$4\frac{1}{4}$
Depth in inches.	$4\frac{3}{4}$–$5\frac{1}{4}$	4–$4\frac{1}{2}$	$3\frac{1}{2}$–4

more than $\frac{3}{8}$ inch deep, and the edges and corners to be unchipped and unbroken.

(*b*) "Durax" block or cubes are ordinarily specified to have six irregular but approximately square surfaces, the edges of which measure from $2\frac{3}{4}$ to 4 inches with a maximum variation of not more than $\frac{3}{4}$ inch for cubes used on any one city block.

312. Joints. For a standard block 10 inches long and 4 inches wide 28.5 will be required per square yard with an average joint of $\frac{3}{8}$-inch width. The joint area per square yard will then amount to 156 square inches or about 12 per cent of the total area. The joint volume per square yard for a 5-inch block is then 780 cubic inches, but this may be reduced from 10 to 20 per cent by ramming the block into the cushion. Upon this basis and allowing for surface wastage or cover, Fig. 37 shows the approximate range in quantities of joint filling materials required per 100 linear feet of pavement of different widths. Quantities of joint filling materials for the smaller sizes of stone block, including irregular sets of Durax, will vary considerably from the values shown in this diagram.

The amounts per square yard may be ascertained by dividing the values for nine-foot width by 100. If in the case of bituminous grout it is desired to ascertain the number of tons required, reference may be made to Fig. 7 for the purpose of translating the values in gallons of bituminous material to tons.

313. Visual Inspection. Stone block should be subjected to careful visual inspection in order to cull out and reject those which are off size or defective, as defined by specifications. Whether or not they have been inspected at the plant they should again be inspected after delivery, at place of use, during laying and after ramming. In addition to dimensional limitations (§ 311) specifications require the block to possess certain qualities and to be free from defects. Thus, the kind of stone may be specified and the block may

be required to be of medium-sized grain, showing an even distribution of constituent minerals. They should be of uniform quality and texture throughout, and free from seams, scales or disintegrated material.

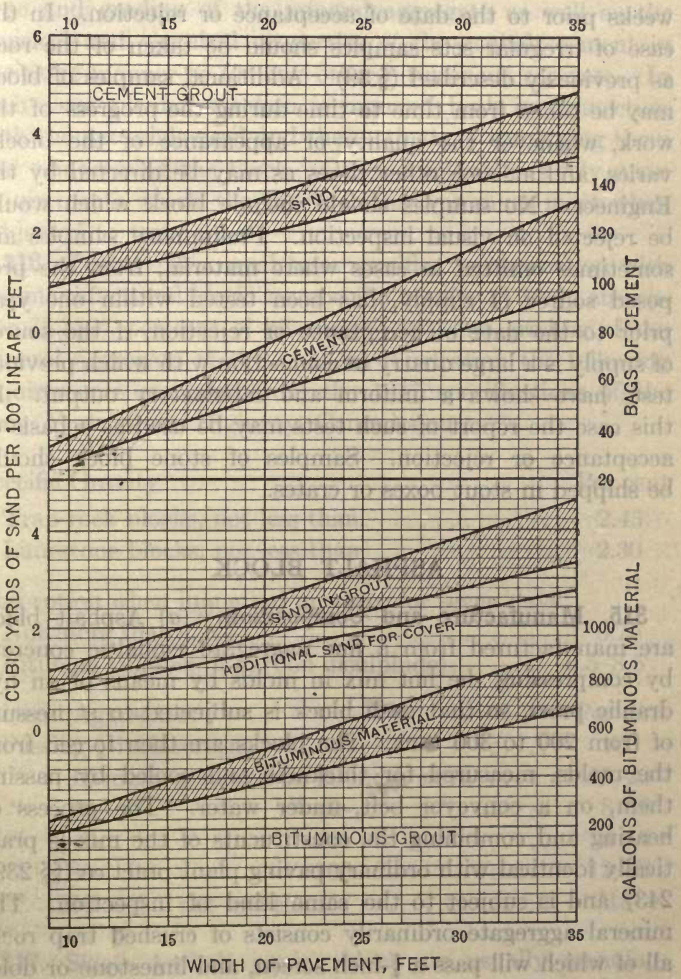

Fig. 37 Quantities of Materials Required for Filling Joints in Stone Block Pavements

314. Sampling. Stone block may be sampled for quality and size either at the quarry or at point of delivery. A preliminary sample for quality, consisting of at least four blocks of common size, should be submitted at least two weeks prior to the date of acceptance or rejection. In the case of irregular sets samples should be taken of the rock as previously described (§ 39). Additional samples of block may be taken from time to time during the progress of the work, whenever the quality or appearance of the blocks varies, and at such other times as may be directed by the Engineer. No samples should include block which would be rejected on visual inspection. Preliminary samples are sometimes omitted in cases where material, from the proposed source of supply, has been tested within one year prior to the date of acceptance or rejection, if the source of supply is a large quarry in connection with which previous tests have shown a uniform and satisfactory output. In this case the report of such tests may be used as a basis of acceptance or rejection. Samples of stone block should be shipped in stout boxes or crates.

ASPHALT BLOCK

315. Manufacture and Composition. (*a*) Asphalt block are manufactured from a fine aggregate asphaltic concrete by compressing the hot mix in molds by means of an hydraulic press, so that each block is subjected to a pressure of from 200 to 300 tons. The blocks are then forced from the molds, measured for thickness and cooled by passing them, on a conveyor belt, under water. The process of heating and combining the constituents of the mix is practically identical with ordinary paving plant practice (§§ 239–243) and is subject to the same kind of inspection. The mineral aggregate ordinarily consists of crushed trap rock, all of which will pass a ¼-inch screen, and limestone or dolomite dust. Limestone is also used to some extent for the

coarser part of the aggregate. The asphalt cement is similar to that used in sheet asphalt construction but usually harder or of lower penetration (§ 280).

(*b*) Specifications for asphalt block sometimes limit the type and grading of the mineral aggregate as well as the physical and chemical properties of the asphalt cement in the same manner as for any other bituminous concrete. In such cases plant inspection is required both in connection with the materials used and the methods of combining them and compressing the block. Other specifications rely upon requirements which the block themselves must meet when subjected to test.

316. Tests. The usual tests specified in connection with the manufactured block are specific gravity (§ 383), absorption (§ 382), per cent of bitumen (§ 133) and grading of the mineral aggregate (§ 371). As an illustration the following requirements are cited from the 1917 specifications of the New York State Highway Commission.

Specific Gravity:	Per cent
Trap rock blocks, not less than	2.45
Limestone blocks, not less than	2.30
Absorption when immersed in water for seven days:	
Not more than	0.75
Bitumen (soluble in carbon disulphide)	6.5–8.5

Mineral Aggregate:	Per cent
Passing $\frac{1}{4}$-inch screen	100
" 10-mesh, retained on 20-mesh sieve	15–20
" 20- " " " 40- " "	8–16
" 40- " " " 80- " "	8–14
" 80- " " " 200- " "	12–18
" 200- " not less than	18

317. Size. Asphalt paving block are usually manufactured 12 inches in length and 5 inches in width. Three

standard depths are used, 2, $2\frac{1}{2}$ and 3 inches. Specifications for size usually allow a tolerance of $\frac{1}{4}$ inch in length and $\frac{1}{8}$ inch in width and depth, from specified dimensions. As good block are smooth and regular they may be set very close together so as to produce but little joint space. A cover of sand spread $\frac{1}{4}$ of an inch thick should be more than sufficient to fill all voids in a three-inch block pavement and less may ordinarily be used. On heavy grades and under heavy traffic conditions, the use of anchor blocks is sometimes specified. Such blocks are of the same size and shape as the ordinary block but have a steel form, of special shape, imbedded in their lower surface so as to project about one-half inch into the mortar cushion on which they are laid. At suitable intervals a row of anchor blocks is laid across the pavement to prevent undue movement in the adjoining areas.

318. Inspection and Sampling. (*a*) Depending upon specification requirements, the inspection of asphalt block pavements may involve the services of a plant Inspector as well as a street Inspector, as in the case of bituminous concrete. The duties of an asphalt block plant Inspector are in every way similar to those of the paving plant Inspector except that in addition to the regular duties of the former he may be required to make determinations of specific gravity (§ 383) and absorption (§ 382). Both plant and street Inspector should subject each shipment of block to careful visual inspection, in order to cull out any which are off size (§ 317) or defective under specification requirements. All block should be uniform in texture and shape, with parallel faces, free from warp, checks or cracks. The edges should be straight, sharp and unchipped and the corners unbroken.

(*b*) One sample consisting of two block should be taken from every car load received unless the block have been inspected and sampled at the plant, in which case at least one sample should be taken from every 100,000 block or less. Sample blocks should be free from all defects which

would prevent their passing visual inspection. Samples should be carefully packed and shipped in stout wooden boxes.

WOOD BLOCK

319. Manufacture. Wood paving block are manufactured from a variety of woods such as long-leaf yellow pine, Douglas fir, tamarack, Norway pine, hemlock and black gum. The first mentioned wood has probably been used to the greatest extent and is ordinarily preferred although specifications usually allow a variety of woods to compete. As the blocks are laid with the end of the grain up, long planks are first sawed and surfaced to suitable width and thickness so that when cut the cross section will give the length and width of blocks which are desired. The block are formed by sawing the plank into such sections as will produce the desired depth of block. In the ordinary plant the block are then loosely and irregularly stacked in metal cages, carried on narrow gauge cars, and are run into long horizontal iron cylinders which are then closed tight at both ends. These are known as treating or creosoting tanks and are equipped with steam coils. Vertical tanks are used to a limited extent, in which case the block are carried to the tank directly from the saw by means of disc conveyors.

(*b*) Various methods of preliminary treatment are given the block before they are impregnated with creosoting oil but in general the process is as follows: After the block have been placed in the tank, which is then tightly closed they are subjected to the action of live steam at 104° to 116° C. for from 2 to 4 hours after which the steam is exhausted and a vacuum of not less than 22 inches is maintained for at least 1 hour. At the end of the vacuum treatment and while the vacuum is still on, creosoting oil is run into the tank, until the cylinder is completely filled, and heated to a temperature of from 84° to 104° C. Additional oil is then forced in until pressure is gradually developed, not to exceed 50 pounds per square inch at the end of the

first hour nor 100 pounds at the end of the second hour. Finally, a pressure of from 100 to 150 pounds per square inch is maintained until the required amount of oil, usually from 16 to 20 pounds per cubic foot, has been absorbed by the block. The oil is then run out of the tank and a vacuum of at least 20 inches is applied for not less than 30 minutes. This is sometimes followed by a short steaming process after which the treated block are discharged from the tank.

(*c*) The first steam treatment of the block serves two purposes: first, to heat the block so as to receive the oil without chilling it; second, to regulate the moisture content of the wood which, as charged into the tank, may be either too dry or too wet. The vacuum treatment serves to remove air and excess moisture from the wood cells so that the oil will be properly absorbed.

320. Requirements. (*a*) No reliable tests for creosoted wood block have as yet been devised and, in order to secure a satisfactory product, specifications usually contain rather rigid requirements relative to manufacture, which necessitate the services of a plant Inspector (§ 323). As an example, the method of treatment just described (§ 319*b*) is included in the 1916 specifications of the American Society for Municipal Improvements.

(*b*) In addition to listing the types of wood allowed, only one of which should be used in any given contract, these specifications require that the blocks must be sound, square butted, square edged, free from unsound, loose or hollow knots, knot holes and other defects such as shakes, checks, etc., that would be detrimental to the block. The number of annual rings in the 1 inch which begins 2 inches from the pith of the block is specified at not less than 6, measured radially, provided, however, that blocks containing between 5 and 6 rings in this inch shall be accepted if they contain 33.3 per cent or more summer wood. In case the block does not contain the pith, the 1 inch to be used should

begin 1 inch away from the ring which is nearest to the heart of the block. It is further specified that the blocks in each charge shall contain an average of at least 70 per cent of heartwood and that no one block shall be accepted that contains less than 50 per cent of heartwood.

(*c*) Specifications for size of wood block vary considerably but, in general, they run from 5 to 10 inches in length and from 3 to 4 inches in width. The depth should preferably be one-half of the length and at least $\frac{1}{4}$ of an inch greater or less than the width. Between individual block a variation of $\frac{1}{16}$ inch in depth and $\frac{1}{8}$ inch in width from the dimensions specified is usually allowed. For heavy traffic, block 4 inches in depth are commonly used and for moderate traffic, $3\frac{1}{2}$ inches.

(*d*) Requirements for creosoting oils (§ 105) have been fairly well standardized by the 1916 specifications of the American Society for Municipal Improvements and by Tentative Standard D52–18T of the American Society for Testing Materials. Both of these specifications require the use of either a coal-tar paving oil or a distillate oil although an additional specification for water-gas tar is also included. Limits of physical and chemical properties of these three types of preservatives as determined by laboratory tests are shown under Typical Material Requirements (§ 414). A number of the requirements serve the purpose of identification only. The direct suitability requirements limit the amount of water and free carbon or insoluble material which tends to prevent proper absorption by the block, and also the presence of an undue amount of readily volatile constituents.

321. Joints. Wood block are ordinarily set close together in the pavement so that joints do not exceed $\frac{1}{8}$ inch in width, except in the case of lug blocks when the joint is about $\frac{1}{4}$ inch. The joint space per square yard will, of course, vary with the size of block used (§ 320*c*). Allowing $\frac{1}{8}$-inch joints between blocks $8\frac{1}{2}$ inches long, 4 inches wide and

$4\frac{1}{4}$ inches deep, about 36.5 will be required per square yard, the joint area being 4.4 per cent, and the joint volume 278 cubic inches per square yard. If the cushion material is assumed to occupy $\frac{1}{4}$ inch of depth, the joint volume is 262 cubic inches per square yard. Upon this basis and allowing

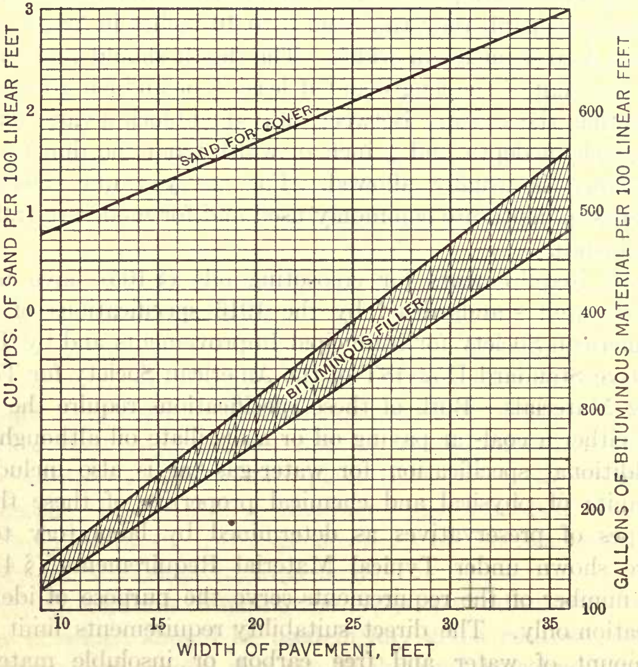

Fig. 38 Quantities of Materials Required for Filling Joints in Wood Block Pavements

for surface wastage or excess, Fig. 38 shows the approximate number of gallons of bituminous material required to fill 100 linear feet of pavement of different widths and also the amount of sand cover required. The amounts of bituminous material and sand required per square yard may be ascertained by dividing the values for nine-foot width by 100. If it is desired to ascertain the number of tons required refer-

ence may be made to Fig. 7 for the purpose of translating the values in gallons to tons.

322. Inspection. (*a*) Wood block should be subjected to visual inspection both at the plant, and after delivery at place of use, during and after laying and rolling, in order to cull out and reject those which are off size or defective under specification requirements (§ 320). Blocks should be laid as soon after treatment as possible. Specifications of the American Society for Municipal Improvement, adopted in 1916, require that if they cannot be laid within 2 days, provision should be made to prevent them from drying out, by stacking them in close piles under cover, and sprinkling them thoroughly with water at intervals. They should be thoroughly sprinkled about two days before laying.

(*b*) Plant inspection not only involves visual examination of the finished block, as covered in the preceding paragraph, but also inspection of the untreated wood and the details of manufacture included in specification requirements. This may necessitate certain tests in connection with plant operation (§ 323). Culling of the finished block will be considerably reduced by inspecting the planks before they are sawed, so as to reject those which would produce blocks that could not meet the specifications. It is also advisable to sort acceptable plank, so as to obtain for any one charge of block, lumber of approximately uniform weight per cubic foot. This is indicated by the spacing and texture of the annual rings as shown by the end sections of the plank. Each annual ring is composed of a dense area, caused by slow winter growth, and a lighter and more porous area of relatively rapid summer growth wood. In connection with treatment, records should be kept of the number of cubic feet of wood in each charge, the weight of oil absorbed by each charge as determined from tank readings, and of the temperature, time and pressure of each phase of treatment, as determined by thermometers and gauges which are a part of the plant equipment. The volume of

oil forced into the wood is indicated by the difference in level of oil in the storage tank between the time that pressure is applied and when the pressure is released. The weight of oil absorbed is then ascertained from its specific gravity (Fig. 7) as determined by laboratory test (§ 121). The weight of oil per cubic foot of wood is calculated by dividing the total weight of oil absorbed by the number of cubic feet of wood in the charge. As a check upon such measurements and calculations the Inspector should occasionally make a test upon a cubic foot sample of block which is suspended in a wire cage in the treating tank throughout the entire treatment. The difference in weight of sample before and after treatment indicates the weight of oil absorbed per cubic foot. In this test (§ 381) the amount of moisture in both the untreated and treated block should be taken into account as treatment may either remove or add to the total moisture content.

(*c*) In addition to ascertaining the amount of oil absorbed by the block, the plant Inspector should determine whether or not satisfactory penetration and diffusion has been secured. To determine this, at least 25 block should be taken from different parts of each charge and sawed in half at right angles to the fiber. Specifications of the American Society for Municipal Improvement require that the oil must be diffused throughout the sapwood and if more than one of the 25 blocks show untreated sapwood, the charge shall be retreated. It is further specified that the surface of blocks after treatment shall be free from deposit of objectionable substances.

323. Sampling. (*a*) Except for his own tests to determine weight of oil absorbed per cubic foot of wood (§ 381) and diffusion of the oil (§ 322*c*) the plant inspector is required to sample only the preservative oil, which should be subjected to laboratory tests before use. The following methods for sampling creosote oil has been adopted by the American Society for Testing Materials, under Standard

Method D38–18, in cases where the oil is being loaded or discharged by means of a pump. "A $\frac{1}{2}$-inch sampling pipe should be inserted in the line through which the oil is being pumped, on the discharge side of the pump, preferably in a rising section of the pipe line. This sampling pipe shall extend one halfway to the center of the main pipe and with the inner opening end of the sampling pipe turned at an angle of 90 degrees and facing the flow of the liquid. This pipe shall be provided with a plug cock and shall discharge into a receiver of 50 to 100 gallons capacity. The plug cock shall be so adjusted that, with a steady continuous flow of the oil, the receiver shall be filled in the time required to pump the entire shipment. The receiver shall be provided with a steam coil sufficient to keep the contents at a temperature not exceeding 120° F. Immediately upon completion of the pumping, the contents of the receiver shall be very thoroughly agitated and a duplicate one-quart sample taken immediately for the test. The amount of the drip sample collected shall not be less than one gallon for each 1000 gallons of oil handled, except in the case of large boat shipments, where a maximum of 100 gallons is sufficient."

(*b*) In the 1916 specifications of the American Society for Municipal Improvements the following method of taking storage tank samples is specified. "In sampling from storage it is necessary to secure samples from different levels, and where possible this may be done by means of small outlet cocks, at regular intervals, from the top to the bottom of the storage tank. In such cases about one gallon of tar or oil shall be drawn from each outlet cock and thoroughly mixed and a portion taken for testing. The stream from each cock shall always be allowed to flow for sufficient length of time to enter the outlet pipe and nipple before commencing to collect the sample. When tanks have no outlet cocks, a vessel having a string attached to the cork may be lowered to measured depth, representing a number

of different levels in the tank, and the cork removed when the vessel has reached the proper level. These samples shall be combined for an average as above."

MAINTENANCE

324. Methods. (*a*) Maintenance of brick or block pavements may involve repairs to joint filler or cracks, replacement of individual block or areas of block, surface treatment with bituminous material, or sometimes entire relaying with most of the block originally used in the pavement.

(*b*) Failures of cement grout filler in limited areas may be repaired by carefully chipping out the grout for a depth of not less than ½ inch, carefully cleaning the joints, drenching them with water and applying new grout as in original construction. Extensive failures are tedious and difficult to repair, but after thorough cleaning a bituminous surface treatment may improve conditions. Wear of bituminous joints is more easily remedied by reapplication of the bituminous filler, so as to bring the joints flush with the adjacent pavement.

(*c*) Failure of individual block or a number of adjacent block may require replacement, in which case the defective block should be carefully removed so as to disturb as little as possible the surrounding area. A stone chisel should be used to cut out cement grout joints at such places. Replacements should be made only with whole block so as to form a dovetailed patch when a number of block are involved. The new block should be laid exactly as in original construction and the cushion or bed adjusted so that their upper surface is brought flush with the surrounding area.

(*d*) Cracks in cement-grouted brick pavements may be repaired with bituminous material as described for concrete pavements (§ 231*a*).

(*e*) Areas which have heaved, because of swelling or expansion, require relaying with the use of a bituminous

filler or the insertion of expansion joints at proper intervals. If the old block are to be replaced they should first be carefully cleaned and culled, to reject chipped, broken or inferior block.

(*f*) When a pavement through long hard service has worn unevenly and the surface is rough, treatment with cut-back asphalt or tar is made so that with the application of cover a bituminous mat is produced. Sometimes the old pavement is made to serve as a foundation for another type of pavement. Occasionally the old pavement is torn up and the blocks cleaned, sorted to lots of uniform thickness and relaid bottom side up. In the case of old granite block pavements, the block are often recut by breaking them in half and dressing the broken surfaces. The cut block are then relaid with the fresh cut surface up.

325. Inspection. Inspection of maintenance will usually be the same as for joint filling (§§ 328–330), surface treatment (Chapter IX) or original construction. The extent of sampling will depend upon the amount of work and material involved.

INSPECTOR'S EQUIPMENT

326. Construction. The street Inspector may require the following equipment for the inspection of brick and block pavement.

For Measurements:
- A 50-foot steel tape.
- A pocket rule (§ 387).
- A straight edge (§ 357).

For Sampling:
- A supply of close-woven bags for grouting sand.
- A ball of stout twine.
- A supply of eyelet tags for identification information.
- A supply of 1 quart tin cans with tight fitting covers for sampling cement or bituminous materials.

A supply of gum labels.

A few stout boxes may be required occasionally for shipping samples of block.

For Testing:

A thermometer (§ 386) if bituminous filler is used.

A set of field screens and sieves with suitable openings as may be covered in specifications for cushion or grouting sand (§ 371).

A spring balance with pan capacity of 200 grams (§ 371).

For Records and Reports:

A field diary and pencil.

A supply of report forms (§ 404).

A carbon paper for duplication of reports.

In addition to the above the plant Inspector for asphalt block may need any or all of the equipment of a paving plant Inspector (§ 253). For wood block he will need, in addition to the above, a complete test outfit for determining the weight of oil per cubic foot of wood (§ 381). For samples of block to be shipped to the laboratory a number of stout wooden boxes or crates will be required.

327. Maintenance. For extensive replacements, the Inspector's equipment will be the same as for construction. For maintenance with bituminous materials, it will be the same as for surface treatment (§ 191).

CHAPTER XV

INSPECTION OF MISCELLANEOUS WORK AND MATERIALS

BITUMINOUS EXPANSION JOINTS

328. General Characteristics. In highway construction expansion joints are usually filled with bituminous material which will compress or yield as the joint tends to close with expansion of the surrounding pavement and thus relieve it of compressive strains which might otherwise crush the paving material or cause it to bulge or heave. The filler should preferably adhere firmly to the sides of the joints, so that when contraction occurs it will stretch as the joint opens and thus keep the joint water-tight. Expansion is ordinarily caused by heat and absorption of water, while contraction is caused by cold and drying out. Longitudinal joints are usually placed at the junction of pavement with curb or gutter and are not subjected to as severe traffic conditions as transverse joints. The latter, in particular, should be carefully maintained by the addition of new filler as the old is worn away or disintegrated. Each joint in a bituminous-filled brick or block pavement serves as an expansion joint and sometimes, in an otherwise monolithic structure, two or more courses of bituminous-filled block are inserted at intervals in the pavement in place of the usual single joint. There are two types of fillers, known as poured joint and prepared joint fillers.

329. Poured Joints. (*a*) Blown asphalt (§ 97) or tar pitch (§ 104) is ordinarily used for filling joints by the pouring method. The joint space is formed by means of strips

of wood or metal of suitable thickness which are inserted during construction and later withdrawn, thus leaving empty slots. Care should be taken that these slots are kept perfectly clean until the filler is poured in. Accumulations of dirt, sand or pebbles in the slots will not only interfere with properly filling the joints but may pack so as to interfere with expansion of the pavement. The bituminous material is usually heated in kettles, transferred to hand pouring cans with narrow spouts or outlets, which may be inserted in the top of the joint spaces, and allowed to flow into the joints until a little more than flush with the surrounding surface. A slight surplus of hot material is necessary in order to allow for shrinkage upon cooling. The finished joint should, however, be brought practically flush with the pavement and a hot smoothing iron may be used for this purpose in case the joint is overfilled. It is important that the filler be heated sufficiently to prevent its chilling too rapidly upon contact with the pavement, but care should be exercised that it is not injured by overheating. Ordinarily asphalt fillers should not be heated to over 400° F. or tar fillers to over 325° F. At least one sample of filler should be taken from every shipment received (§ 115). The chemical and physical properties of asphalt and tar filler as determined by laboratory tests, which are commonly covered by specifications, are shown under Typical Material Requirements (§§ 411, 413).

(*b*) The gallons of bituminous material needed in filling joints is ascertained by dividing the number of cubic inches of joint space by 231. If it is desired to ascertain the number of tons of filler, the cubic inches of joint space should be multiplied by the specific gravity of the material and the resulting product multiplied by 0.0000181.

330. Prepared Joints. Prepared joint fillers (§§ 97, 104) are manufactured in strips of the thickness which is desired for the width of joint. These strips are sometimes wider than the depth of the joint if a composition is used which

contains no fabric. Such fillers are placed during construction of the pavement and if they project above the surface are eventually flattened out with a hot smoothing iron, which not only brings them flush with the surrounding pavement but seals the top of the joint and renders it waterproof. If the filler projects more than $\frac{3}{8}$ inch above the surface it should be trimmed. A hot shovel, to the bottom of which metal cleats have been riveted, is sometimes used for trimming joints. Prepared joint fillers should be sampled as previously described (§ 117).

PAVING ADJACENT TO CAR TRACKS

331. Materials. Adjacent to, and between, street car tracks, brick or block are frequently laid irrespective of the paving material proper. This is ordinarily considered good practice, especially in the case of bituminous pavements, unless the track construction is so rigid that vibration is reduced to a minimum. When very rigid the pavement proper may be carried to the rail. Even then many engineers consider that brick or block should preferably be laid between all rails if the tracks run along the center of the pavement. Special forms of brick or block, known as rail block, are frequently used directly against the rail. These block are designed to produce a close smooth joint with rail, so constructed or set that a perfectly rectangular block would produce a poor joint.

332. Methods. Between the pavement proper and the rail, brick are often set for a width of 18 inches or more so as to extend beyond the ties. They are laid upon a concrete base and may be filled with cement grout or bituminous material. Cement mortar or bituminous mastic is used as a filler between the web and lip of the rail so as to give the adjacent block a firm setting. Between pavement and rail three or more courses of block may be laid longitudinally, while between the rails the courses are laid trans-

versely. If a bituminous pavement is carried directly against the rail, it is usually laid slightly higher than the rail. Especial attention should be paid to obtaining as tight a rail joint as possible so as to prevent the entrance of water.

COLD PATCHING

333. Materials. So-called cold patching has become a rather popular method of repairing holes and depressions in bituminous macadam and certain types of bituminous concrete pavements, and its use has been extended to other types of pavement. The patching composition is composed of unheated mineral aggregate mixed with cut-back asphalt (§ 98) or tar (§ 102) or emulsified asphalt (§ 99). To be successful such bituminous material should possess the property of setting up rapidly after the mix is laid. The physical and chemical properties of cold patching materials, commonly covered by specifications, are given under Typical Material Requirements (§§ 409, 410). For repairing bituminous concrete pavements the mineral aggregate should preferably be of the same approximate character and grading as that used in original construction. At least one sample of cold patching material should be taken from each shipment received.

334. Methods. (*a*) Preparation of an old pavement to receive patching mixtures has been covered under maintenance of the various types. The patching composition is usually mixed by hand on a mixing board or platform but sometimes an ordinary concrete batch mixer is used. The mix is proportioned by volume, the proper amount of bituminous material being dependent upon the character and grading of the mineral aggregate. Each particle of aggregate should be thoroughly and uniformly coated so as to produce a homogeneous mixture, but an excess of bituminous material should be avoided or otherwise the mixture will shove under traffic. If an asphalt emulsion is used the

mixing process should be carried only to the point of securing a uniformly coated aggregate, as its nature is such that overmixing may cause the emulsion to separate and deposit a film of water on each mineral particle, thus destroying the bond between asphalt and aggregate. If, however, the separation of the water is allowed to occur gradually by evaporation, the asphalt will adhere firmly to a clean uncoated aggregate.

(*b*) After the mix has been prepared it should be laid in the clean hole and tamped or rolled flush with the surrounding area. The patch should then be sanded or covered with a light dressing of stone chips after which it should be allowed to set up for a short while before being subjected to traffic.

PIPE CULVERTS

335. Clay and Concrete (*a*) Vitrified clay pipe are usually specified to be of the hub and spigot style, sound, thoroughly burned, without warps, cracks or other imperfections and to be fully and smoothly salt-glazed, inside and out, except that the inside of the hub and the outside of spigot may be unglazed for two-thirds of the depth of the hub. If the inside of the hub and the outside of the spigot are completely glazed both should be scored in a number of parallel lines extending completely around the circumference. The pipe should be of such toughness that it may be cut with a chisel and hammer and when struck should give a metallic ring. When broken it should show a dense stonelike structure. Typical specifications of the U. S. Bureau of Public Roads cover the following minimum dimensions for various sizes of pipe:

Size, Inches	Minimum Dimensions		
	Length, Feet	Thickness, Inches	Depth of Hub, Inches
12	2	1	3
15	2	$1\frac{1}{4}$	3
18	2	$1\frac{1}{2}$	$3\frac{1}{4}$
20	2	$1\frac{2}{3}$	$3\frac{1}{2}$
22	2	$1\frac{5}{6}$	$3\frac{3}{4}$
24	2	2	4
27	$2\frac{1}{2}$	$2\frac{1}{4}$	4
30	$2\frac{1}{2}$	$2\frac{1}{2}$	4
33	$2\frac{1}{2}$	$2\frac{5}{8}$	5
36	$2\frac{1}{2}$	$2\frac{3}{4}$	5
42	$2\frac{1}{2}$	$3\frac{1}{2}$	5

(*b*) Concrete pipe are usually specified to be dense, smooth and free from any imperfection that would impair their strength. The concrete should be mixed in the proportion of 1 part standard Portland cement (§ 64), 2 parts sand (§ 223), and $1\frac{1}{2}$ parts clean pea gravel, all of which will be retained on a $\frac{1}{4}$-inch screen. The concrete should be thoroughly mixed with water and tamped into proper-shaped forms. The use of reinforcing metal is ordinarily specified for all sizes above 12 inches, and the type of joint is also specified. Typical specifications of the U. S. Bureau of Public Roads cover the following requirements in connection with thickness and the weight of triangular mesh, or other approved, reinforcement for various sizes of pipe.

Inside Diameter	Minimum Thickness, Inches	Triangular Reinforcement, 4″-mesh, Minimum Weight
12	2	No Reinforcement
18	2	0.30 Lbs. per sq. ft.
24	$2\frac{3}{4}$	0.40 " " " "
30	3	0.40 " " " "
36	$3\frac{1}{4}$	0.50 " " " "
42	$3\frac{1}{2}$	0.60 " " " "
48	4	0.60 " " " "

(*c*) Standard specifications for drain tile manufactured from shale, fire clay, surface clay and concrete have been adopted by the American Society for Testing Materials under serial designation C4–16. These specifications cover limitations for tests of strength, absorption, and freezing and thawing for three classes of tile known as farm drain tile, standard drain tile and extra quality drain tile, the class to be specified by the purchaser. These specifications require that a sample for physical test shall consist of five individual tile. Visual inspection is covered in considerable detail. Among the points covered, the following are probably the most important from the standpoint of highway inspection. Unless otherwise specified, all drain tile should be of approximately circular cross section and approximately straight, with ends sufficiently regular and smooth to admit of making close joints by turning and pressing together adjoining tile. Sizes should be designated by the internal diameter. Tile smaller than 12 inches in diameter should have a minimum length of 12 inches. From 12- to 30-inch tile should have a length not less than their diameter and if larger than 30-inch the length should be not less than 30 inches. They should be uniform in structure throughout, reasonably smooth on the inside and free from cracks or checks which would appreciably affect their strength. They should not be chipped or broken in such manner as to decrease their strength materially, or admit earth into the drain. They should be vitrified or hard burned and when stood on end in a dry condition and tapped with a light hammer they should give a clear ring. For extra quality tile a tolerance of 3 per cent in average diameter below that specified is allowed. Sixty-five per cent of the thickness of wall is given as an allowable variation between maximum and minimum diameters of the same tile or average diameters of adjoining tile. The tolerance for straightness is an allowance of 3 per cent of the length. The allowable thickness of exterior blisters, lumps

and flakes which do not weaken the tile and are few in number is given as 15 per cent of the thickness of wall. The allowable diameters of such blisters, lumps and flakes is 10 per cent of the internal diameter.

336. Metal Pipes. (*a*) Corrugated metal pipes are constructed of both iron and steel and the chemical composition of the base metal is sometimes specified in great detail. The minimum weight per square foot of spelter coating, or galvanizing, is also specified as determined by laboratory test. Typical specifications of the U. S. Bureau of Public Roads allow either iron or steel as the base metal without any definite chemical requirements and require not less than 2 ounces of prime spelter per square foot of sheet, uniformly distributed over the surfaces of the sheets of metal. They further require that the sheets of metal before galvanizing shall be smooth and free from blisters, seams and pits, and shall be not less than 16-gauge U. S. Standard for pipe of 20-inch diameter or less, and not less than 14-gauge U. S. Standard for pipe between 20 and 36 inches in diameter. They also require that the spelter shall be applied in such manner that it will not peel off during fabrication, transportation or laying of the pipe, and that any uncoated spots due to poor workmanship, rough handling or any other reason shall be sufficient cause for rejection. Other points which may be determined by visual inspection are as follows: "The corrugations shall be not less than $2\frac{1}{2}$ inches nor more than 3 inches from crest to crest and shall have a depth of not less than $\frac{1}{2}$ inch nor more than $\frac{5}{8}$ inch. All joints shall be even and close and the jointed pipe shall be straight, circular in section, true and rigid. In the longitudinal joints, rivets shall be driven in the valley of each corrugation; in the transverse joints rivets shall be uniformly spaced not more than 6 inches apart. The rivets shall be at least one inch from the edge of the sheet and shall be driven in such manner as to draw the sheets tightly together and fill the rivet holes com-

pletely. All rivets shall be thoroughly galvanized and shall be not less than $\frac{5}{16}$ inch in diameter, with neat semi-spherical or flat heads. The heads shall have a diameter of not less than one and one-eighth times the diameter of the rivet, plus $\frac{1}{8}$ inch, and all flat heads shall have a thickness not less than four-tenths that of the diameter of the rivet. Field connections shall consist of bands not less than 8 inches in width so fabricated that a secure and firm connection of the sections of pipe may readily be made. The diameter of the pipe shall be understood to mean the clear diameter." Unless the pipe has been inspected at the plant the Inspector should take a sample from each size pipe in each consignment, but in no case should less than 3 samples be taken from each consignment. Each sample should be cut out with a cold chisel and should measure about 6 inches square.

(*b*) Cast-iron pipe are usually made with bell and spigot joints. They should be straight and the inner and outer surfaces should be true concentric cylinders. All samples should be smooth, free from scales, lumps, blisters, sand holes and defects of every nature which would unfit the pipe for the use for which it is intended. Each pipe should be coated inside and out with a bituminous paint. Typical specifications of the U. S. Bureau of Public Roads give the following minimum thickness and weight per foot of cast-iron pipes of various sizes, and allow a tolerance of 5 per cent on minimum weight.

Inside Diameter	Minimum Thickness, Inches	Minimum Weight per cu. ft., Pounds
12	0.54	72.5
14	.57	89.6
16	.60	108.3
18	.64	129.2
20	.67	150.0
24	.76	204.2
30	.88	291.7
36	.99	391.7

337. Joints. For cementing pipe joints, cement mortar, consisting of 1 part of standard Portland cement and 2 parts of concrete sand (§ 223), or a bituminous joint filler is used.

CONCRETE FOR MISCELLANEOUS STRUCTURES

338. Classes of Concrete. Concrete for structures is usually divided into two or more classes which are designated by letter as Class A, Class B, etc. Different proportions of standard Portland cement, fine aggregate and coarse aggregate, and frequently different size or grading limitations for fine and coarse aggregate are specified for each class. Both proportions and grading limitations are selected with reference to the character and importance of the structure in which the concrete is to be used. The maximum size fragment of coarse aggregate may also be determined in reinforced structures by the minimum space between reinforcing bars or the minimum space between surface and reinforcing metal. The proportioning and mixing of concrete for structures, as well as the inspection of work and sampling of materials, is in general similar to that described for concrete foundations and pavements (Chapter XI).

339. Field Test for Cement. In case a very limited amount of concrete is to be used in structures of minor importance, such as head walls for pipe culverts, and the cement has not been previously tested, the Inspector may make the following test. A small amount of the cement should be kneaded with enough water to form a stiff paste, which is formed into a ball about $1\frac{1}{2}$ inches in diameter. The ball should then be placed under a damp cloth and at intervals tested with the point of a lead pencil to see that it does not set too rapidly (§ 80). The ball should be allowed to remain under the damp cloth over night and should then be placed for three hours in a pan of boiling water. If it is then hard and free from check marks the cement is sound. While this test may serve as an emergency method for small structures,

it should never be relied upon for important concrete structures where the higher classes of concrete are used.

340. Forms. Structural concrete is usually placed and tamped in specially constructed forms which are often supported by falsework. All forms should be designed and constructed so that they may be removed without injuring the concrete. As an example of specification requirements for form work the following is taken from typical specifications of the U. S. Bureau of Public Roads: "The material to be used in the forms for exposed surfaces shall be sized and dressed lumber, or metal in which all bolt and rivet heads are countersunk, so that in either case a plain smooth surface of the desired contour is obtained. Undressed lumber may be used for backing or other unexposed surfaces. The forms shall be built true to line and braced in a substantial and unyielding manner. They shall be mortar-tight and, if necessary to close cracks due to shrinkage, shall be thoroughly soaked with water. Forms for reëntrant angles shall be chamfered and for corners shall be filleted. Dimensions affecting the construction of subsequent portions of the work shall be carefully checked after the forms are erected and before any concrete is placed. The interior surfaces of the forms shall be adequately oiled, greased or soaped to insure the non-adhesion of mortar. Form lumber which is to be used a second time shall be free from bulge or warp and shall be thoroughly cleaned. The forms shall be inspected immediately preceding the placing of concrete, and any bulging or warping shall be remedied and all dirt, sawdust, shavings or other débris within the forms shall be removed." The placing of concrete within forms should be as continuous as possible, and wherever new concrete is placed against concrete which has reached its initial set, such juncture should be considered and planned for as a construction joint. Regular expansion joints are provided for in certain concrete structures, as in the case of pavements (§§ 328–330). The time and condition under which forms

may be removed, depending upon the type of structure, should be covered by the specifications and closely observed by the Inspector. After removal of the forms the exposed surface may be smoothed up by filling small cavities with cement mortar and rubbing the surface free of form marks with a wooden float and clean water. Various kinds of surface finish may also be specified.

341. Waterproofing. Structural concrete is sometimes waterproofed by incorporating hydrated lime in the mix to the extent of about 10 per cent of the volume of cement used. The lime is ordinarily required to meet the specifications of the American Society for Testing Materials adopted as Standard C6–15 (§ 226).

IRON AND STEEL

342. Reinforcing. (*a*) Metal reinforcement for concrete structures usually consists of square twisted, deformed or plain steel bars, expanded metal, wire mesh or wire cloth, or structural steel shapes, as specified or called for on the plans. The Inspector should see that it is placed in accordance with plans and specifications.

(*b*) Steel bars may be made from billet steel or from rerolled rail. Specifications for the former have been adopted as Standard A15–14 and for the latter as Standard A16–14 by the American Society for Testing Materials. These specifications cover various chemical and physical properties, which can only be determined by laboratory test and inspection, and sampling for work of any magnitude should be conducted at the point of manufacture. The Highway Inspector should, however, subject the reinforcement to visual inspection and, if laboratory test records are not available, he may sometimes subject specimens to the cold bend test by means of the equipment operated by the contractor for bending bars. From billet steel three grades are manufactured, which are known as structural steel, inter-

mediate and hard. The desired grade should be indicated in the specification. The cold bend test is made by bending the test specimen around a pin for 180 degrees or 90 degrees as called for, under which test the specimen should show no cracking on the outside of the bent portion. In the following table are shown the diameters of pins and the degrees of bending required of the various types and grades of bars, with diameters under $\frac{3}{4}$ inch and diameters of $\frac{3}{4}$ inch or over. In this table t represents the diameter of the specimen which is bent.

COLD-BEND TEST REQUIREMENTS

Type and Grade of Bar	Thickness or Diameter of Bar			
	Less than $\frac{3}{4}$ Inch		$\frac{3}{4}$ Inch or Over	
	Deg. Bend	Diam. Pin	Deg. Bend	Diam. Pin
I. Plain Bars:				
Billet, Structural	180	t	180	t
Billet, Intermediate	180	$2t$	90	$2t$
Billet, Hard	180	$3t$	90	$3t$
Rail..................	180	$3t$	90	$3t$
II. Deformed Bars:				
Billet, Structural	180	t	180	$2t$
Billet, Intermediate	180	$3t$	90	$3t$
Billet, Hard	180	$4t$	90	$4t$
Rail..................	180	$4t$	90	$4t$
III. Cold Twisted Bars:				
Billet..................	180	$2t$	180	$3t$
IV. Hot Twisted Bars:				
Rail				

Twisted bars are required to have one complete twist in a length not over 12 times the thickness of the bar. All bars are specified to be free from injurious defects and to have a workmanlike finish. The weight of any lot of bars should not vary more than 5 per cent from the theoretical weight of that lot.

(*c*) Expanded metal and wire mesh or wire cloth reinforcement, in addition to limitations of physical properties determined by laboratory test, are usually specified to have a certain minimum weight per 100 square feet. Such weight may be determined by the Inspector.

343. Structural Steel. Structural steel and iron are manufactured and fabricated in accordance with plans and specifications. Plain structural shapes, fabricated structural steel and steel rivets, as well as steel and iron castings, are usually required to meet certain standard specifications adopted by the American Society for Testing Materials. Inspection of structural steel for important work should be conducted at the plant.

MASONRY

344. Types of Masonry. (*a*) There are two types of masonry commonly used in connection with highway structures, brick masonry and rubble masonry. Brick are usually laid in cement mortar. Rubble, laid in cement mortar, is known as cement rubble masonry, and laid without mortar, as dry rubble masonry.

(*b*) Brick are usually specified as to quality, size and sometimes color and are required to have straight parallel edges and square corners. They should be hard burned throughout, of uniform texture and free from cracks or injurious defects. They are sometimes culled with a view to using the most uniform brick in the face of the masonry. The only test to which they are ordinarily subjected is one for absorption, and specifications often require that when thoroughly dried and weighed they shall not absorb more than 10 per cent of water upon 24 hours' immerson. They may also be required to give forth a clear ringing sound when struck sharply together.

(*c*) Rubble stones should be sound and free from structural defects, earth, clay or other foreign substances. Selected

stones roughly squared and pitched to line are usually used at angles and ends of structures. The approximate dimensions of stones in the face of the masonry are generally specified but smaller stones are allowed for filling joints.

345. Mortar. Mortar for laying brick and rubble masonry is ordinarily composed of one part of standard Portland cement to 3 parts of sand, while for pointing a 1 : 1 mortar is used. Hydrated lime is ordinarily added to the extent of ten per cent by volume of cement. A full mortar bed is used for the brick or rubble stone which should be thoroughly soaked before laying. Brick are laid in the mortar so as to break joints about ½ brick between courses. On exposed faces of all masonry the joints should be cleaned or raked out and pointed with the 1 : 1 mortar.

PRESERVATIVE COATINGS

346. Paints. Wood and steel highway structures are usually coated with paint which should be carefully specified as to composition. The paint is ordinarily composed of a pigment, such as a metallic oxide, sulphate, or carbonate, ground in linseed oil and thinned with turpentine which serves as a drier. They are sometimes purchased ready for use and sometimes a paint paste is purchased and mixed with thinner, to proper consistency, on the job. The Inspector should take and submit to the laboratory a one-pint sample of prepared paint or of each individual constituent used on the job from each shipment received.

347. Dips. Specifications frequently require that posts which are to be partially buried in the ground, such as posts for guard rails, should be painted with or dipped in a bituminous paint for the depth to which they are to be buried. A coal tar paint is frequently specified for this purpose. A one-quart sample of such paints or dips should be taken from each shipment received and submitted to the laboratory for examination.

NON-BITUMINOUS DUST PREVENTIVES AND BINDERS

348. Calcium Chloride. Calcium chloride is a chemical substance obtained in large quantities as a by-product mainly in the manufacture of soda from salt. It may be obtained as a solid or in concentrated solution, but the granulated solid is the most common form in which it is now used for highway purposes. Calcium chloride has a strong affinity for water and will absorb moisture from the atmosphere to such an extent that in humid weather it will dissolve in the water thus absorbed. It has been used to a considerable extent as a dust preventive for broken stone or gravel roads and to a limited extent in the construction of such roads. For surface treatment when used in granulated form it may be spread by means of shovels at the specified rate of application, usually from 1 to 2 pounds per square yard, but the use of a fertilizer distributor is more satisfactory. In solution it is applied by means of an ordinary street sprinkler. Its effect as a dust preventive is much more lasting than water but reapplications are necessary at intervals, depending upon climatic and other local conditions. A one-pound sample of the solid or a one-quart sample of the liquid should be taken from each shipment received and submitted to the laboratory.

349. Sodium Silicate. Sodium silicate is a chemical substance commonly sold in the form of a thick syrupy liquid known as water glass. Upon exposure to the atmosphere it precipitates gelatinous silicic acid, and reacts with calcareous rocks to form calcium silicate upon the surface of the rock fragments. It is extensively used as a binder in the manufacture of artificial rock and is used as the basis of a patented road material known as "Rocmac." The Rocmac solution may be mixed with limestone screenings, at the rate of 15 gallons per cubic yard, to form a matrix which is spread upon the road to a thickness of $\frac{1}{3}$ inch

for every 1 inch thickness of broken stone which it is required to bind. Broken stone is then spread and rolled until the matrix works to the top. If desired a mixture of the solution with limestone screenings and broken stone may be prepared in a concrete mixer and the resulting product laid and compacted as in ordinary macadam construction.

350. Waste Sulphite Liquor. In the manufacture of wood pulp, according to the sulphite process a waste liquor is produced in large quantities. By partial evaporation a thick syrupy residue is produced which possesses considerable binding value. Such a concentrated product, known as "Glutrin," is marketed as a road material and has been used to some extent as a dust layer and binder for macadam and gravel roads. It may be diluted with water to any desired extent and applied by means of an ordinary street sprinkler. The proportions of Glutrin and water most commonly used lie between 1 : 10 and 1 : 20. The number of treatments required for a season depends upon traffic and climatic conditions.

CHAPTER XVI

MEASUREMENTS

GENERAL CONSIDERATIONS

351. Purpose of Measurements. Measurements should be taken and recorded by the Inspector for the purpose of ascertaining quantities of materials received and used, or amount of work performed, in accordance with specification requirements. In certain instances measurements may also serve to determine the character of work performed.

352. Classes of Measurement. There are four principal classes of measurement considered in the following paragraphs. These are linear measurement, measurements of area, measurements of volume and measurements of weight. Other classes, such as measurements of temperature and time, require no special comment.

353. Accuracy of Measurements. Measurements made by the Inspector can be accurate only to the extent that they are truly representative. This may necessitate frequent check measurements and recourse to different methods. Thus, the average depth of a pavement can only be ascertained by a number of measurements of depth judiciously made, and accuracy of volume measurements may require checking by measurements of weight. In some instances it may also be necessary to take into account certain factors, such as expansion, contraction or shrinkage, and wastage, which will vary considerably at times even for the same type of work or same class of material. The Inspector's basis of measurement may also differ from that of the Engineer as later explained. All of these facts should be

clearly understood and borne in mind in order to prevent confusion and unnecessary controversy.

LINEAR MEASUREMENTS

354. Length. (*a*) The common unit of measure, for length of highway, is the foot and the basis of measure the center line of the highway surface. On the plans, a horizontal base line is shown or indicated which, commencing at a given zero point, is divided into sections of 100 feet each. The point of juncture of two sections is called a station and is given a number known as a station number. Thus, station 1 indicates 100 feet measured horizontally from the zero point on the base line; station 2 indicates 200 feet, etc. Intermediate points in a station are expressed in feet and decimal parts of a foot. Thus, Station 12 + 50.1 means 1250.1 feet measured horizontally from the zero point on the base line. Stations at the center line of the highway are fixed by vertical projections of the base-line stations. It is evident that if the surface of the highway is parallel to the base line or, in other words, is level, station distances on the center line are the same as on the base line and each center-line section is, therefore, 100 feet in length. If, on the other hand, the center line runs at an angle to the base line, or, in ordinary terms, runs up or down grade, station distances on the center line will be greater than on the base line. The actual distance may be calculated, if the difference in elevation between two points on the center line is known and between these points the angle, of the center line to the base line, is a constant. Under such conditions the difference in elevation is called the grade of the road and is expressed in per cent of the corresponding section of base line. Thus, a 5-per-cent grade means a uniform rise or fall of center line of 5 feet per 100 feet of base line. Up to 5-per-cent grades the difference in center-line and base-line distances is within the allowable limit of error

of ordinary measurement and need not be considered. Above 5-per-cent grades it becomes noticeable. The differences between stations, distances and center-line distances for various grades is shown in the following table:

Per cent Grade	Feet, Center Line per Station
5	100.13
6	100.18
7	100.25
8	100.32
9	100.40
10	100.50
11	100.60
12	100.72

(*b*) On tangents or straight sections of highways, stations at the side of the highway are the same distance apart as at the center line. On curves, however, the distances vary according to the radius of the curve at the side station or the distance of the side station from the center of the circle bounded by a completion of the curve. For this reason, all measurements of length should be made along the center line.

355. Width. The width of a highway is measured at right angles to the center line on tangents, and on the radius of curves. The width of pavement proper is the shortest distance between the inside edges of shoulders, gutters, or curbs, as the case may be, but the effect of crown is so slight that no important error is made by measuring directly across the surface for crowns of $\frac{1}{2}$ inch or less. For crowns greater than $\frac{1}{2}$ inch a plumb line should be used in connection with the tape.

356. Thickness. (*a*) Thickness or depth of pavement is, in most cases, much more difficult to control, and measure with accuracy, than width or length. Uniform depth of a pavement true to grade and line can only be secured by

similar conditions in the subgrade or underlying course. Differences in thickness at different locations in the cross section, such as center and sides, are often specified and must necessarily exist unless the underlying surface carries the same crown as the pavement proper. In either case, frequent measurements of depth at representative points should be made by the Inspector.

(*b*) Uncompacted thickness is often gauged, in the case of materials which are spread, by the use of wooden cubes of suitable dimensions which are laid at intervals across the highway on the subgrade or underlying course. These cubes are moved along as the work progresses. This method is satisfactory if the subgrade or underlying course is free from irregularities, but, if irregularities exist, they are apt to be carried up to the surface of the pavement. It is ordinarily considered better practice to set gauge strings longitudinally at the sides and center of the highway.

(*c*) For some classes of work a template is used not only for securing the desired contour but also the desired thickness. In the latter case the template is worked at right angles to the center line of the highway from side forms, curbs, or edging set at the proper elevation. Distance from points on the under face of the template to the subgrade or underlying surface should be measured from time to time as a check.

357. Testing Contours and Surface Irregularities. Specifications frequently require that finished surfaces shall be tested with a straightedge, or with a template cut to the crown shown on the cross-section drawings. In the case of a straightedge, its length and method of use are specified. If a template is used, the surface is tested at right angles to the center line. If template and straightedge are both specified, the straightedge is used for testing the surface longitudinally, in which case it may be eight feet or more in length. If a straight edge only is specified, it is usually made about 2 feet in length and the tests are made by lay-

ing it, in various directions, on the surface. Maximum allowable depth of depressions, under such test, is specified, and all depressions approximating the specified limit should be measured by the Inspector.

MEASUREMENTS OF AREA

358. Surface Areas. (*a*) The common unit of measure for surface area of highway is the square yard. In estimat-

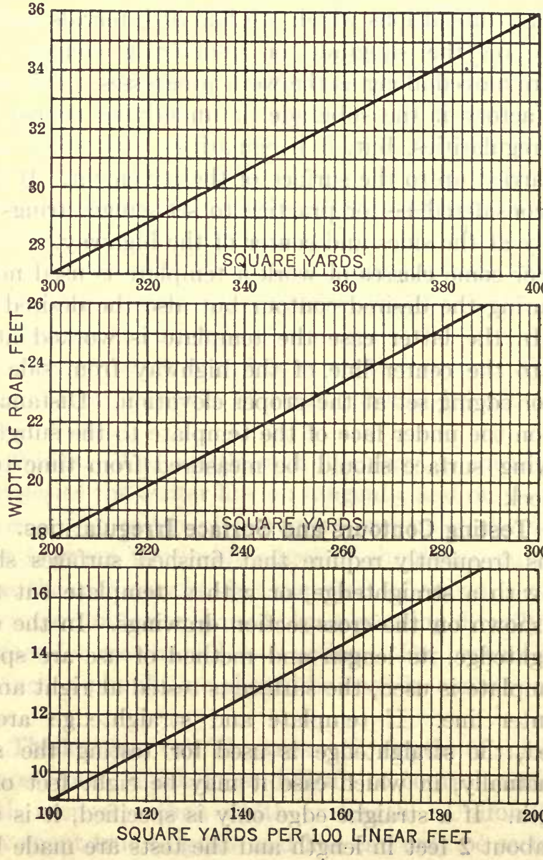

Fig. 39 Area of 100 Linear Feet of Road

ing and checking quantities of materials used, the Inspector is interested only in actual surface yardage. Payment is, however, frequently made upon horizontal measurement so that there may be the same relative discrepancy between actual and horizontal area measurements as shown under measurements of length (§ 354). Thus, the horizontal yardage of 900 feet of highway 18 feet wide on a 7-per-cent grade is

$$\frac{900 \times 18}{9} = 1800 \text{ sq. yds.}$$

while the actual yardage is

$$\frac{9 \times 100.25 \times 18}{9} = 1804.5 \text{ sq. yds.}$$

(*b*) The number of square yards of surface per 100 feet of highway of various widths is shown in Fig. 39. The number of square yards per foot of highway may also be obtained from this diagram by pointing off two decimals for the values given. The equivalent of 100 square yards of surface, in linear feet of highway, and the equivalent of 1 square yard, in linear inches of highway are shown in Figs. 40 and 41 for different widths of road.

359. Crown Sections. (*a*) In estimating the volume of material in a given length and width of highway, it is necessary to know the depth. Unless the depth is the same throughout the width, this involves a determination of average depth or else a determination of the area of the cross section of the highway. The latter method is most convenient when the crown is curved and may best be used by considering crown section areas, first of all, as distinct from total end section areas. The crown of a road or pavement is usually expressed as average difference of elevation in fractions of an inch per foot of width. Thus a crown of $\frac{1}{2}$ inch means an average drop, from peak of crown to edge of road, of $\frac{1}{2}$ inch per foot. Except on sharp curves where the surface is sometimes made to slope in a single

direction, the peak of the crown is carried along the center line of the highway.

(*b*) While various crown formulas have been used, the three most common types of crown are the intersection of

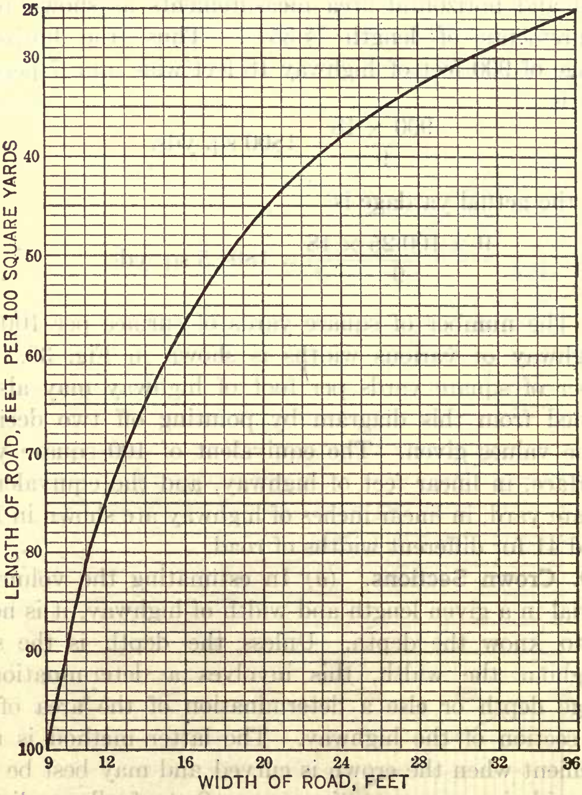

Fig. 40 Length of Road Represented by 100 Square Yards

two straight lines, the parabola and the circular arc. The crown section is the area enclosed by connecting the lower extremities of the crown with a straight line. In the case of the crown, made by the intersection of two straight lines, this will produce a triangle, the area of which is equal to

the width of the road multiplied by one-half the difference in elevation between the center and sides. In the case of a parabolic crown, the area of the crown section is equal to the width of the road multiplied by two-thirds the difference in

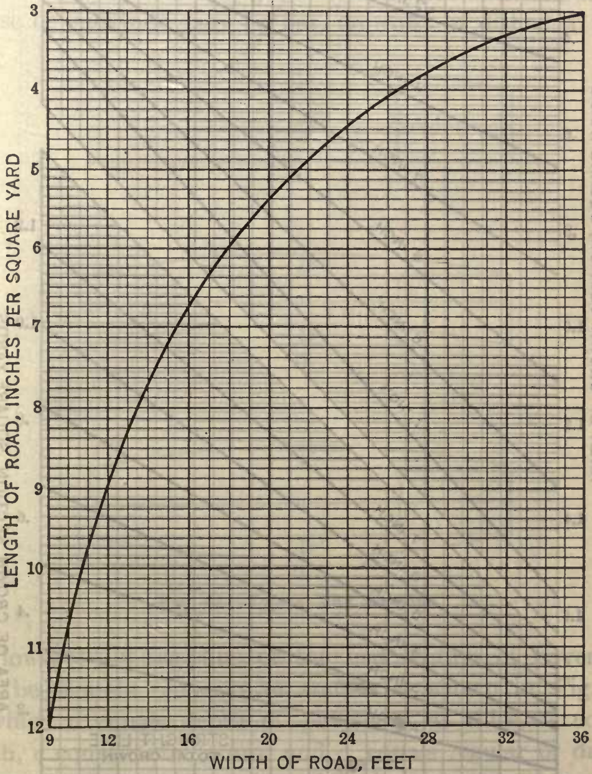

Fig. 41 Length of Road Represented by One Square Yard

elevation between the center and sides. No such definite relation exists for the circular arc crown but ordinarily it is so close to the parabolic that for all practical purposes the same formula may be used. Upon this basis Fig. 42 shows the crown section areas for pavements of different width,

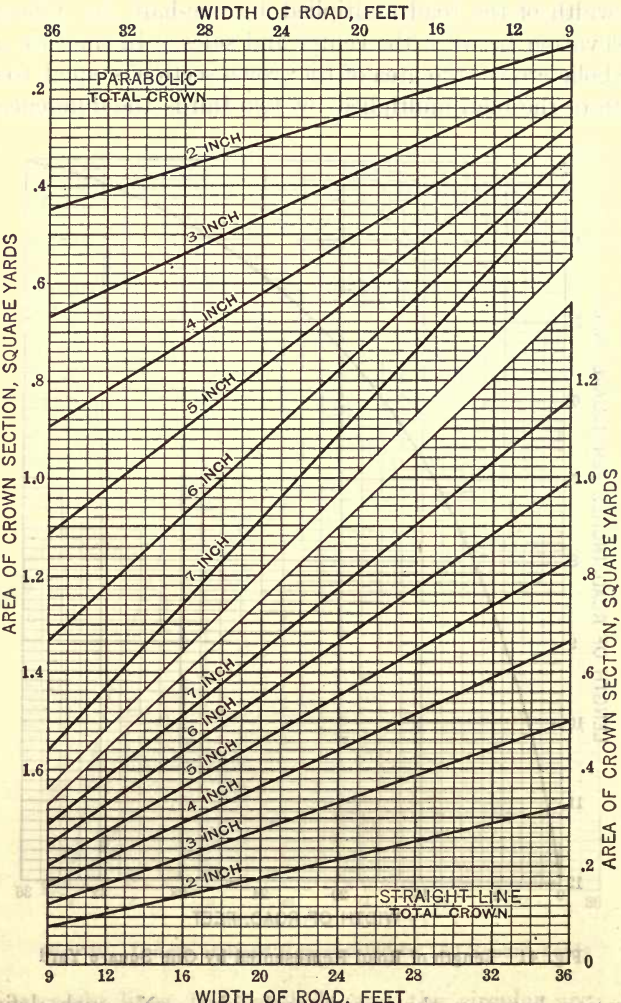

Fig. 42 Crown Section Areas

for various differences in elevation between the center and sides. This difference is called the total crown.

360. End Section Areas. (*a*) The end section of a pavement represents an area bounded at the top by the crown of the pavement, at the bottom by the line of juncture with the underlying course or subgrade, and at the sides by the inside faces of shoulders, gutters or curbs. The underlying course or subgrade may be flat, crowned or dished so that

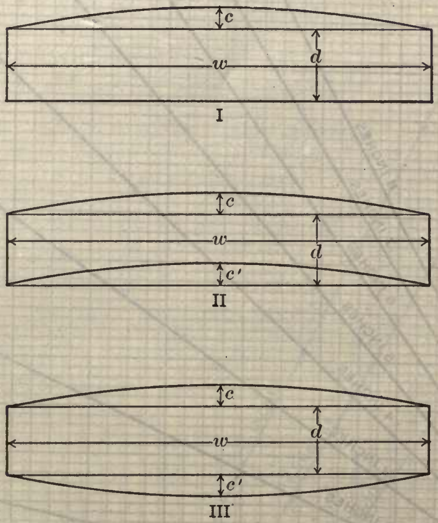

Fig. 43 Typical End Sections

the lower bounding line of the end section of pavement may be straight, concave or convex as shown in Fig. 43, in which d equals depth of pavement at sides, w equals width, c equals total crown and c' equals regular or dished crown, as the case may be, of underlying course or subgrade.

If the crown of the pavement is the same as that of the underlying course or subgrade, the top and bottom lines of the end sections are parallel and the thickness of the pavement is, therefore, uniform. In such case, the end section may be considered as a rectangle with dimensions equal to

the width and depth of pavement. Its area is, therefore the product of width times depth or $w \times d$.

(*b*) In Case I, Fig. 43, the end section area is equal to the area of the rectangle $w \times d$ plus the area of the crown section, having a maximum depth of c. In Case II the end

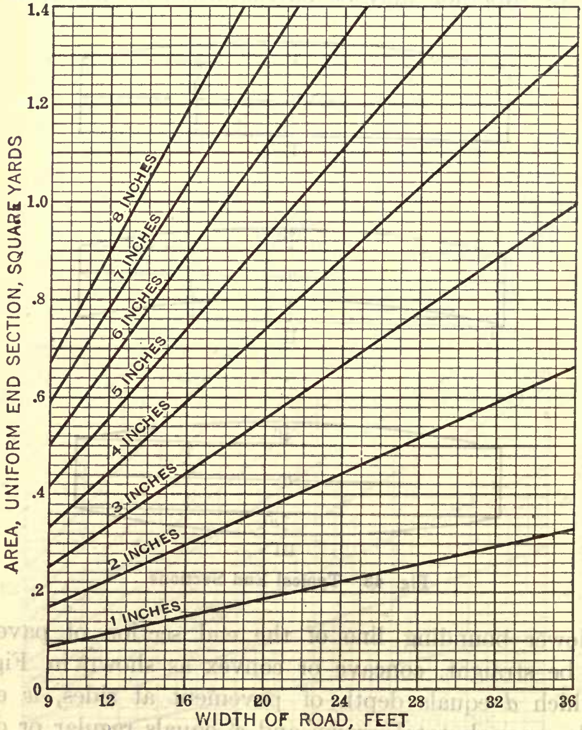

Fig. 44*a* Areas of End Sections of Uniform Thickness

section area is equal to the area of the rectangle $w \times d$, plus the crown section area, with a maximum depth of c, minus the crown section area with a maximum depth of c'. It is, of course, evident that if in this case both crown sections are equal (§ 360*a*) the end section area is equal to the rectangle $w \times d$. In Case III, the end section area is

equal to the area of the rectangle $w \times d$ plus the crown section area with a maximum depth of c, plus the crown section area with a maximum depth of c'.

(*c*) Figs. 44*a* and 44*b* show the end section areas for various uniform thicknesses of different widths of pave-

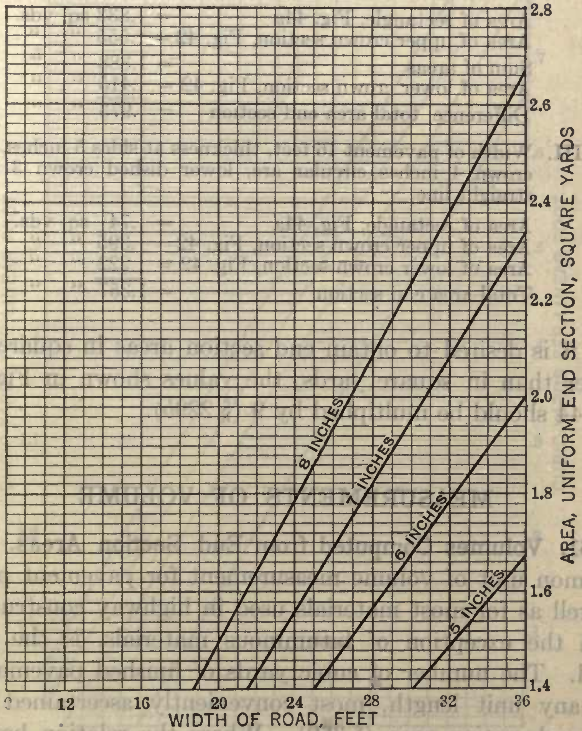

Fig. 44*b* Areas of End Sections of Uniform Thickness

ment which may be considered as represented by the rectangular area of Fig. 43. The use of these figures in quickly ascertaining end section areas is illustrated by the following examples:

Case I. Width of pavement 20 feet, thickness of sides 6 inches, crown 2 inches parabolic, subgrade flat.

Area of rectangle, Fig. 44a	=	1.11	sq.	yds.
Area of crown section, Fig. 42	=	.247	"	"
Total area, end section	=	1.357	"	"

Case II. Width of pavement 30 feet, thickness at sides 3 inches, upper crown 4 inches straight line, lower crown 3 inches straight line.

Area of rectangle, Fig. 44a	=	.833	sq.	yds.
Area of upper crown section, Fig. 42	=	.555	"	"
Sum of areas	=	1.388	"	"
Area of lower crown section, Fig. 42	=	.415	"	"
Difference, total area end section	=	.973	"	"

Case III. Width of pavement 16 feet, thickness at sides 5 inches, upper crown 4 inches circular arc, lower dished crown 3 inches straight line.

Area of rectangle, Fig. 44a	=	.74	sq.	yds.
Area of upper crown section, Fig. 42	=	.395	"	"
Area of lower crown section, Fig. 42	=	.222	"	"
Total area end section	=	1.357	"	"

If it is desired to obtain end section areas in square feet, rather than in square yards, the values shown in Figs. 42 and 44 should be multiplied by 9 (§ 229*b*).

MEASUREMENTS OF VOLUME

361. Volumes Computed from End Section Areas. The common unit of volume measurement for pavement proper as well as for most materials used in highway construction, with the exception of bituminous materials, is the cubic yard. The number of cubic yards of finished pavement is, for any unit length, most conveniently ascertained from the end section area (§ 360). Where the relation between uncompacted and compacted material is known, this method is also useful in checking quantities of various materials placed on the road. Volumes in cubic yards per linear foot of pavement with end section areas up to 4 square yards are shown in Fig. 45, which will be found useful to the Inspector in checking his other measurements.

362. Volumes Measured in Excavation. Quantities of materials are sometimes measured in excavation by taking cross-section levels at suitable intervals and computing

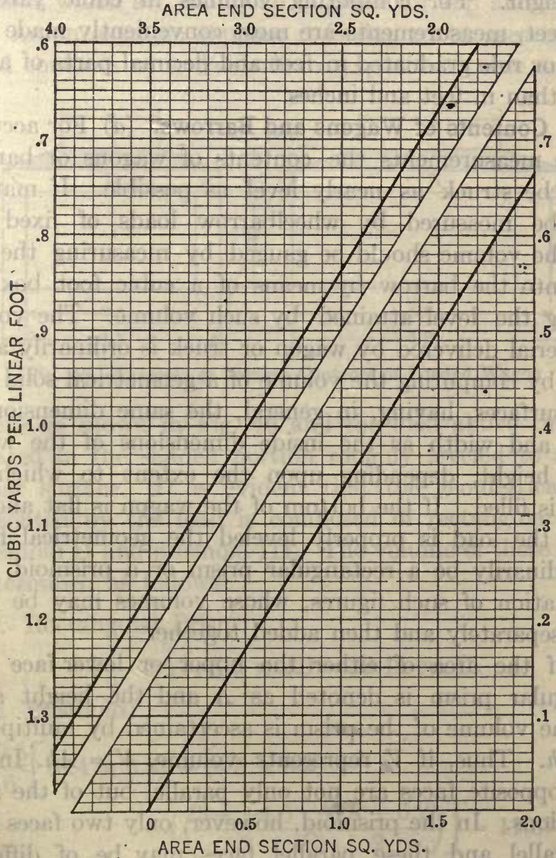

Fig. 45 Volumes per Linear Foot Represented by Various End Section Areas

volumes from the end areas. Such measurements and computations are ordinarily made by the Engineer and not by the Inspector.

363. Capacities of Rectangular Containers. The capacity of a rectangular container is the product obtained by multiplying together the inside dimensions of length, width and height. For computing volumes in cubic yards or cubic feet, measurements are most conveniently made with a tape or rule graduated in feet and decimal parts of a foot rather than in feet and inches.

364. Contents of Wagons and Barrows. (*a*) For accurate volume measurements the contents of wagons or barrows should be struck as nearly level as possible. If material is to be measured by wheelbarrow loads of fixed volume, the volume should be gauged by measuring the material into the barrow by means of a cubic foot box and marking the level attained by such volume. The volume of material delivered by wagon or truck is ordinarily ascertained by computing the volume of a geometrical solid with plane surfaces, having, in general, the same dimensions of length and width as the inside dimensions of the wagon and a height, depending upon the extent to which the wagon is filled. If the bottom of the wagon is flat and the top of the load is properly leveled the geometrical figure will ordinarily be a rectangular prism or a prismoid, or a combination of such figures, whose volumes may be computed separately and then added together.

(*b*) If the area of either the upper or lower face of a rectangular prism is denoted as A and the height as h, then the volume of the prism is ascertained by multiplying A by h. Thus, if V represents volume, $V = Ah$. In the prism opposite faces are not only parallel but of the same dimensions. In the prismoid, however, only two faces need be parallel and these parallel faces may be of different dimensions. If the parallel faces are at the top and bottom and their respective areas are denoted as A and a and the vertical distance between, or the height as h, then

$$V = \frac{h}{6}(A + a + 4m).$$

In this formula m denotes the area of a section midway between and parallel to the top and bottom. If both top and bottom are rectangles then area m is a rectangle with dimensions which are the mean of those for top and bottom.

(*c*) As an example suppose it is desired to ascertain the loaded contents of a flat-bottom wagon with side and end

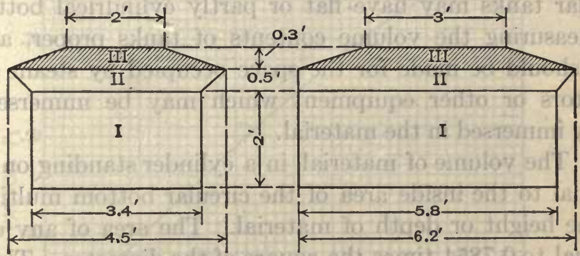

Fig. 46 Example of Volume Contents of Loaded Wagon

sections as shown in Fig. 46 and the load above the sides indicated in the shaded portion roughly leveled to a rectangular surface. It is evident that the geometrical solid represented by the load is composed of rectangular prism I, prismoid II and prismoid III. The volume of these figures is determined as follows:

I. Rectangular Prism:

$$V = 3.4 \times 5.8 \times 2.0 = 39.44 \text{ cu. ft.}$$

II. Prismoid:

$$V = \frac{0.5}{6}\left[(3.4 \times 5.8) + (4.5 \times 6.2) + 4\left(\frac{3.4 + 4.5}{2} \times \frac{5.8 + 6.2}{2}\right)\right] = 11.87 \text{ cu. ft.}$$

III. Prismoid:

$$V = \frac{0.3}{6}\left[(4.5 \times 6.2) + (2 \times 3) + 4\left(\frac{4.5 + 2.0}{2} \times \frac{6.2 + 3}{2}\right)\right] = 5.83 \text{ cu. ft.}$$

The total volume is then $39.44 + 11.87 + 5.83 = 57.1$ cu. ft. or $\frac{57.1}{27} = 2.1$ cu. yds.

365. Capacity of Tanks. (*a*) Tanks for storing or heating bituminous materials are, in the main, either cylindrical or rectangular. Cylindrical tanks may have flat, or partly spherical ends or bottoms, as the case may be, and rectangular tanks may have flat or partly cylindrical bottoms. In measuring the volume contents of tanks proper, allowance should be made for the space occupied by steam coils, agitators or other equipment which may be immersed or partly immersed in the material.

(*b*) The volume of material, in a cylinder standing on end, is equal to the inside area of the circular bottom multiplied by the height or depth of material. The area of any circle is equal to 0.7854 times the square of the diameter. Thus, if the inside diameter of a tank is 4 feet and the depth of material in the tank is 6 feet, the volume of material is equal to $0.7854(4 \times 4) \times 6 = 75.398$ cubic feet $= 75.398 \times 7.48 = 563.98$ gallons. (§369.)

(*c*) The volume of material, in a cylinder lying horizontally on its side, is equal to the inside length of the cylinder times the inside area of the circular end, if the cylinder is filled. If it is partially filled, then the volume is equal to the length times the area of the segment of a circle represented by the end section of the material. If the height of liquid is calculated as a decimal fraction of the diameter of the circle, the diagram shown in Fig. 47 may be used to obtain a factor which in the following formula will give the volume in gallons of material.

$$V = 7.48F_1 \times D^2 \times L.$$

In this formula V equals volume in gallons, D equals diameter of cylinder in feet, L equals length of cylinder in feet, and F_1 equals factor obtained from Fig. 47.

(*d*) Many horizontal cylindrical tanks have partly spherical or bumped ends, the radius of the bump being the same

as the diameter of the tank. Accurate calculation of volume contents then becomes more complicated but a rapid method has been developed by Howell,[1] in which certain factors are

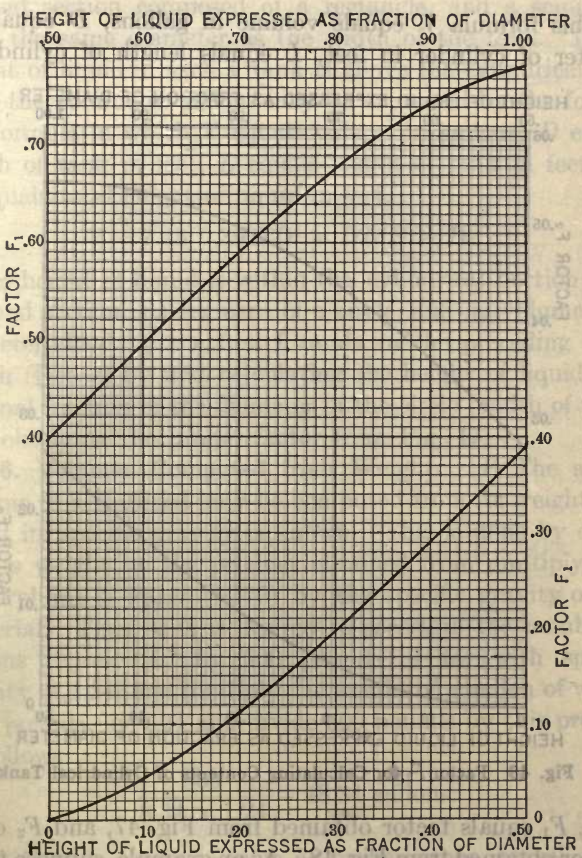

Fig. 47 Factor F_1 for Calculating Contents of Cylindrical Tanks

obtained from curves shown in Figs. 47 and 48. To obtain the factors from these curves it is first necessary to ascertain the height of material as a decimal fraction of the diameter

[1] *Jour. of Industrial & Engineering Chemistry*, May, 1916, p. 430.

of the tank. The following formula is then used to compute the volume in gallons of material.

$$V = 7.48D^2(LF_1 + 2DF_2).$$

In this formula V equals volume in gallons, D equals diameter of cylinder in feet, L equals length of cylinder in

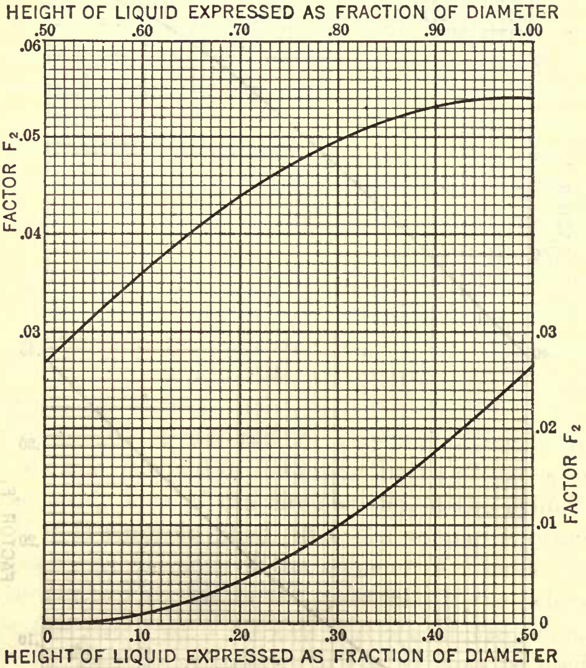

Fig. 48 Factor F_2 for Calculating Contents of Cylindrical Tanks

feet, F_1 equals factor obtained from Fig. 47, and F_2 equals factor obtained from Fig. 48. As an example, suppose the inside diameter of a tank is 4 feet, its cylinder length 10 feet and that the height of liquid is 3 feet. The height of liquid is then $\frac{3}{4}$ or 0.75 of the diameter. From this value in Fig. 47 0.63 is obtained as factor F_1, and in Fig. 48 0.047 is obtained as factor F_2. Using these factors in the above formula, we

have $V = 7.48 \times (4 \times 4)[(10 \times 0.63) + (2 \times 4 \times 0.047)] = 798.98$ gallons.

(*e*) A rectangular tank with semi-cylindrical bottom has an end section composed of a rectangle, and a semicircle with the same diameter as the width of the tank. If the height of liquid in such a tank is above the cylindrical portion, the volume in gallons may be expressed by the following formula in which V equals volume in gallons, D equals width of tank in feet, L equals length of tank in feet and H equals total height of liquid in feet.

$$V = 7.48[0.3927D^2 + DL(H - D)].$$

If the height of liquid is within the cylindrical portion then the end section is a segment of a circle, and its volume may be determined by the first formula in the preceding paragraph (§ 365*c*) by first calculating the height of liquid as a decimal fraction of the diameter of the circle (width of tank) and obtaining the proper factor from Fig. 47.

366. Volumes Computed from Weight. (*a*) The actual volume of a material may be computed from its weight provided its specific gravity is known. This is done by dividing its weight by the product obtained from multiplying a unit volume of water (§ 370) by the specific gravity of the material. Thus, if it is desired to ascertain the number of gallons represented by 500 pounds of tar with specific gravity of 1.24, first multiply the weight of a gallon of water, 8.34 pounds, by 1.24 and divide 500 pounds by this product as follows:

$$\frac{500}{8.34 \times 1.24} - 48.34 \text{ gallons.}$$

(*b*) Certain products, such as broken stone, gravel, sand, etc., occupy an apparent volume which is different from their actual volume. This is due to the fact that unoccupied space or voids exist between the individual fragments. The actual volume of these products is determined in the same manner as described in the preceding paragraph, but in

order to determine the apparent volume it is necessary to know the per cent of voids. If this is known, the apparent volume then equals the actual volume multiplied by 100 and divided by 100 minus the per cent of voids. Thus, if the actual volume is 1 cubic yard and the per cent of voids is 40, the apparent volume is

$$\frac{100}{100 - 40} = 1.66 \text{ cubic yards.}$$

MEASUREMENT BY WEIGHT

367. Weights Computed from Volume. (*a*) The computation of weight from volume involves the specific gravity of the material under consideration. Weight is determined from actual volume by multiplying the volume by the weight of a unit volume of water (§ 370) and multiplying this product by the specific gravity of the material. Thus, if it is desired to ascertain the weight of 2000 gallons of asphalt with a specific gravity of 1.04, the following result is obtained:

$$2000 \times 8.34 \times 1.04 = 17{,}347 \text{ pounds} = 8.674 \text{ tons.}$$

(*b*) If the determination involves apparent volume (§ 366*b*) then the voids in such volume must be taken into account in computing weight. Actual volume equals the apparent volume divided by 100 and multiplied by 100 minus the per cent of voids. Thus, 40 cubic yards of broken stone with 45 per cent voids equals

$$\tfrac{40}{100} \times (100 - 45) = 22 \text{ cubic yards of solid rock.}$$

368. Direct Determination of Weight. (*a*) The direct determination of weight, by means of balance or scales, usually involves the weight of a container, so that two weighings are necessary, that of the empty container, known as the tare weight, and that of the container filled or partly filled, known as gross weight. The weight of material is the difference between gross and tare. If the

same weight of container is used in a series of weighings, the tare becomes a constant, which need not be determined but once, except that it should be checked from time to time. Some scales are furnished with two beams in which case the tare weight may be set on one of the beams and the other used to directly ascertain the weight of material. The use of such scales eliminates the necessity of subtraction.

(*b*) The accuracy of a weighing device may be tested by weighing a known volume of water having, if possible, a calculated weight within the range of weighings which are to be made. The sensitiveness of the device may be tested by adding to, or subtracting from, such volume smaller known volumes of water, about $\frac{1}{100}$ and $\frac{1}{1000}$ of the original volume and noting the difference in scale readings.

EQUIVALENT MEASURES

369. Common Measures. The following equivalents of common measure may be useful to the Highway Inspector. The decimal parts of a foot represented by from 0 to 12 inches is shown in Fig. 49

MEASURES OF LENGTH

Miles	Yards	Feet	Inches
1 =	1760 =	5280	
	1 =	3 =	36
	.0333 =	1 =	12
		.0833 =	1

MEASURES OF SURFACE

Square Yards	Square Feet	Square Inches
1 =	9 =	1296
0.111 =	1 =	144
	0.007 =	1

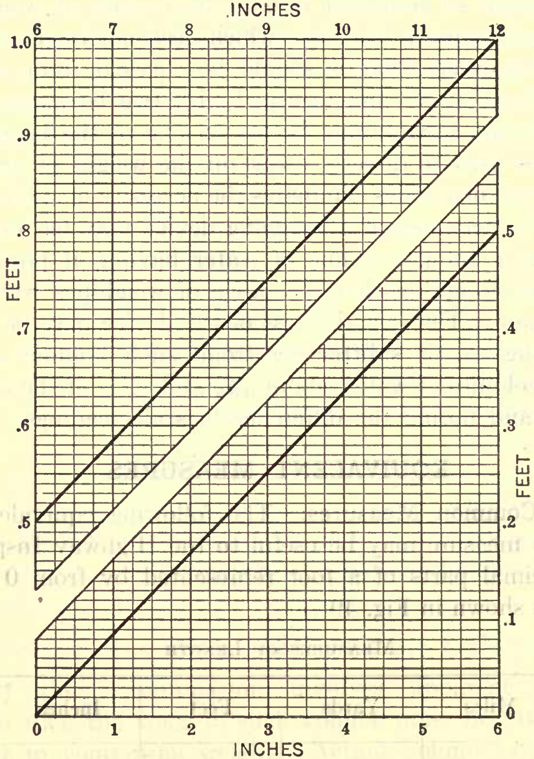

Fig. 49 Equivalents of Inches in Decimal Parts of a Foot

Measures of Volume

Cubic Yards	Cubic Feet	Cubic Inches	U. S. Gallons	U. S. Bushels
1 =	27 =	46,656 =	20.20	
.03704 =	1 =	1728 =	7.48	
		1 =	0.0043	
0.0046 =	0.1337 =	231 =	1 =	0.176
	1.2445 =	2150.5 =	9.31 =	1

MEASURES OF WEIGHT

Long Tons	Tons	Pounds	Ounces	Kilograms	Grams
1 =	1.12 =	2240			
	1 =	2000			
	0.0005 =	1 =	16 =	0.4536 =	453.6
			1 =		28.35
		2.205 =	35.274 =	1 =	1000

370. Weight of Water. The weight of water is ordinarily considered at its point of maximum density 4° C. (39° F.). Owing to the fact that it expands with increase in temperature, the weight of any volume at a higher temperature will be lower than the weight of the same volume at 39° F. At a temperature of 60° F. its weight will be about 0.1 per cent less, and at 75° F. about 0.3 per cent less than at 39° F. These differences are so small that they are ordinarily neglected in computations of volume and weight relations as based upon the specific gravity of other material at normal temperature. The weights of various unit volumes of water, and the volume equivalents of 1 pound of water, are as follows:

1	cubic inch	=	0.0361	pound
27.68	cubic inches	=	1	pound
1	cubic foot	=	62.43	pounds
0.016	cubic "	=	1	pound
1	gallon	=	8.345	pounds
0.1198	gallon	=	1	pound
1	cubic yard	=	1685.6	pounds

CHAPTER XVII

MISCELLANEOUS FIELD TESTING AND SAMPLING EQUIPMENT

TESTS OF MINERAL AGGREGATES

371. Mechanical Analysis and Grading. (*a*) For making mechanical analyses or grading determinations the Inspector should be provided with a suitable set of screens and sieves and a weighing device. Ordinary laboratory apparatus is too cumbersome for convenient field use and the following outfit shown in Fig. 50 has, therefore, been devised for this purpose. A single screen frame is used for all screens. This frame is composed of two circular brass rims about 2 inches high, one fitting snugly within the other. The outer rim has a diameter of 8 inches and carries a narrow shoulder around the inside of the lower edge. The screen plates are thin circular disks $7\frac{15}{16}$ inches in diameter which fit inside of the outer rim and are clamped against the shoulder by means of the inner rim. The screens consist of brass plates $\frac{1}{20}$ inch thick, with punched circular holes. Sieves may consist of flat brass rings to which the wire mesh is permanently fastened although a set of small nestable sieves may be found more convenient. Two spring balances are used with the outfit. One of these balances for weighing fragments larger than $\frac{1}{4}$ inch in diameter has a capacity of 30 pounds with scale divisions of $\frac{1}{10}$ pound and an adjustable pointer which may be set at zero before a weighing is to be made. With this balance weighings are made in a cloth bag which is attached to the hook. A more delicate balance for weighing material smaller than $\frac{1}{4}$ inch in diameter

has a capacity of 200 grams with scale divisions of 1 gram, and carries a small pan in which the material is weighed. A light camera tripod will be found convenient for supporting the balances when in use, but is not absolutely

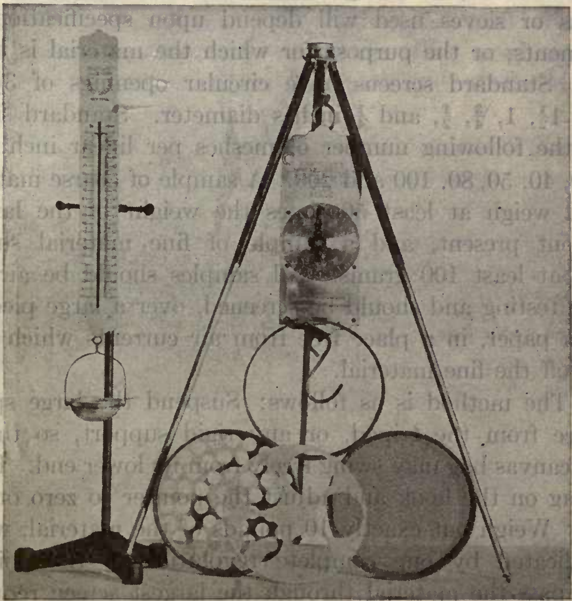

Fig. 50 Field Outfit for Mechanical Analysis

necessary. A complete outfit including all screens and sieve plates, as well as a tripod, weighs approximately 10 pounds and may be packed in a rectangular space 6 × 8 × 17 inches. The weight of outfit may ordinarily be reduced two or three pounds by selecting only those plates which will be needed for a particular job.

(*b*) For testing purposes a sample may be considered as consisting of coarse or fine material, depending upon whether it will practically all be retained upon, or will pass a ¼-inch screen. If there is a substantial proportion of both sizes,

as in the case of bank gravel, it is considered as being a mixture of coarse and fine material. A description of the method of testing such a sample will also illustrate the procedure which should be followed for either coarse or fine material alone, it being understood that the particular screens or sieves used will depend upon specification requirements, or the purpose for which the material is to be used. Standard screens have circular openings of $3\frac{1}{2}$, 3, $2\frac{1}{2}$, 2, $1\frac{1}{2}$, 1, $\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ inches diameter. Standard sieves have the following number of meshes per linear inch: 10, 20, 30, 40, 50, 80, 100 and 200. A sample of coarse material should weigh at least 50 times the weight of the largest fragment present, and a sample of fine material should weigh at least 100 grams. All samples should be air dry before testing and should be screened, over a large piece of manila paper, in a place free from air currents which may carry off the fine material.

(*c*) The method is as follows: Suspend the large spring balance from the tripod, or any rigid support, so that a small canvas bag may swing freely from its lower end. Hang the bag on the hook and adjust the pointer to zero on the scale. Weigh out exactly 10 pounds of the material, which is indicated by one complete revolution of the pointer. Then pass the material through the largest screen required and weigh the amount retained, each $\frac{1}{10}$ pound being recorded as 1 per cent. Do the same with the next largest screen, and so on down to the $\frac{1}{4}$-inch screen. If the maximum size of fragment necessitates more than a 10-pound sample, set aside the material which passes the $\frac{1}{4}$-inch screen and repeat the entire operation with as many 10-pound lots as may be necessary. Then thoroughly mix all of the material which has passed the $\frac{1}{4}$ inch and weigh it. Substitute the small spring balance for the large and weigh out, if possible, exactly 200 or 100 grams of the fine material. Pass this sample through the largest sieve required and weigh the amount retained. Each 2 grams should be recorded as 1

per cent of the fine material, if the original sample weighed 200 grams, or each gram as 1 per cent, if the original sample weighed 100 grams. If a smaller weight is necessary the per cent retained should be calculated. Do the same with the next largest sieve, and so on down to the smallest. If desired the material passing the smallest may also be weighed as a check upon the accuracy of the other weighings. All weighings of fine material should finally be calculated as per cent of the original sample.

(*d*) The entire operation of recording results is illustrated by the following example, which represents the mechanical analysis of an original 20-pound sample of gravel. The operation has been conducted upon two portions of 10 pounds each, which is the most convenient amount to use. It should be noted, however, that the capacity of the large spring balance will allow for either a 20- or 30-pound sample. In the former case, each $\frac{2}{10}$ pound, and in the latter, each $\frac{3}{10}$ pound represents 1 per cent of the sample.

Operation	(1) lb. %	(2) lb. %	Average %
Weight of sample	10	10	
Ret. on 2-inch screen	0.6 = 6	0.2 = 2	4
Pass. 2 in., ret. on 1-in. screen	2.0 = 20	3.0 = 30	25
" 1 " " " $\frac{1}{4}$ " "	3.2 = 32	3.8 = 38	35
Total passing $\frac{1}{4}$-inch screen	4.2 = 42	3.0 = 30	*36

	Grams %	*Factor	% Original Material
Weight of sample passing $\frac{1}{4}$-in. screen	200		
Ret. on 10-mesh sieve	48 = 24	× .36	9
Pass. 10-mesh, ret. on 200-mesh sieve	112 = 56	× .36	20
Passing 200-mesh sieve	40 = 20	× .36	7

Complete Analysis

	Per cent
Retained on 2-inch screen	4
Passing 2 inch, retained on 1-inch screen	25
Passing 1 inch, retained on ¼-inch screen	35
Passing ¼-inch screen, retained on 10-mesh sieve	9
Passing 10 mesh, retained on 200-mesh sieve	20
Passing 200-mesh sieve	7
Total	100

372. Organic Matter in Sand. (*a*) The following field method for determining the existence of harmful organic impurities in sand, for use in cement concrete, has been developed by Committee C-9[1] of the American Society for Testing Materials. For this test it is necessary to have a 12-ounce graduated prescription bottle and a supply of 3 per cent solution of sodium hydroxide. This solution may be prepared by dissolving 28.5 grams (¾ oz. apothecaries' weight) of sodium hydroxide in a quart of water. Solid sodium hydroxide in the form of sticks may be obtained at any drug store and should be kept in a tightly corked bottle. It is the most concentrated form of lye and should be handled with care to prevent burning the skin.

(*b*) To make a test "fill a 12-oz. graduated prescription bottle to the 4½-oz. mark with the sand to be tested. Add a 3-per-cent solution of sodium hydroxide until the volume of sand and solution after shaking amounts to 7 oz. Shake thoroughly and let stand over night. Observe the color of the clear supernatant liquid. If this liquid is colorless, or has a light yellow color, the sand may be considered satisfactory in so far as organic impurities are concerned. On the other hand, if a dark colored solution, ranging from dark red to black, is obtained, the sand should be rejected or used only after it has been subjected to the usual mortar strength tests" (§ 58).

373. Silt in Sand. An approximate volumetric determination of silt in sand may be made by filling a 100-cubic-centimeter graduated glass cylinder, to the 50-c.c. mark,

[1] Proc. Am. Soc. Test. Mat., Vol. 17–1917, Part I, p. 328.

with sand and adding sufficient water to reach the 100-c.c. mark. The contents of the cylinder should then be thoroughly shaken and allowed to settle until the supernatant liquid is clear or nearly so. Any silt which is present will settle as a rather clearly defined layer of fine material on top of the sand. Each 0.1-c.c. volume of this layer represents 2 per cent of the volume of sand. The per cent of silt by weight may vary from 1 to 2 times the per cent by volume.

374. Quality of Gravel Pebbles. A rough determination of the quality of pebbles, in a gravel product, may be made by sorting out and discarding from the total material retained on the $\frac{1}{4}$-inch screen in the mechanical analysis determination (§ 371) all pebbles which are manifestly soft, decomposed or partly disintegrated. A geologist's hammer is then conveniently used in testing out the apparently sound pebbles. Those which are readily broken or, when broken, are found to be composed of inferior sandstone should also be discarded. The remaining pebbles and fragments which are considered of good quality should then be weighed. The difference between this weight and that of the total material retained on the $\frac{1}{4}$-inch screen gives the weight of inferior material which should be calculated upon a percentage basis of the total weight of pebbles.

375. Weight per Cubic Foot. (*a*) The weight per cubic foot of such products as broken stone, broken slag, gravel and sand may be made in a cylindrical, or cubical, measure with a capacity of exactly one cubic foot. A convenient measure for field use may be made from $\frac{3}{8}$-inch poplar. The four sides are exactly one-foot square while the bottom measures $12\frac{3}{4}'' \times 12\frac{3}{4}''$. To prevent warping, the sides and bottom carry tongue and groove battings across the grain. Sides and bottom may be quickly fastened together by means of slotted brass angles and screw projections, attached as shown in Fig. 51. This measure weighs only 6 pounds and when taken apart may be packed in a rectangular space $13'' \times 13'' \times 2\frac{1}{2}''$.

(*b*) The determination is made by first introducing into the measure about $\frac{1}{6}$ of the total amount of material required, care being taken to avoid separation of sizes. The material is then shaken down, by rocking the measure from side to side, until no further settlement takes place. This process is repeated until the measure has been filled to overflowing, after which it is struck level with the top by means of a rule or straightedge. The contents of the box may then be weighed in portions by means of a large spring

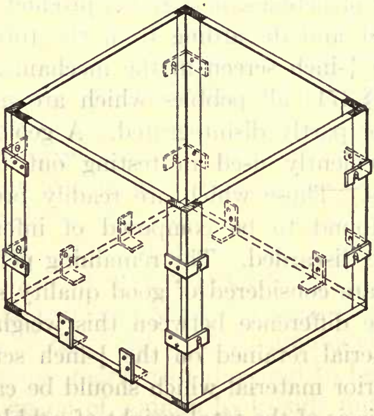

Fig. 51 Collapsible Cubic Foot Measure

balance, such as used for mechanical analysis (§ 371). If, however, large weighing scales are handy, it may be more convenient to weigh the measure before and after filling and to determine by difference the weight of material per cubic foot.

376. Specific Gravity. (*a*) When a material, such as broken stone, is homogeneous in character, an approximate determination of its specific gravity may be made by suspending with a fine thread a fragment, weighing somewhat less than 200 grams, to the pan support of the small spring balance described under mechanical analysis (§ 370). The weight of the fragment in air is then ascertained. The frag-

ment should next be submerged in water and quickly weighed again, care being taken that no air bubbles are held against its surface. If the weight in air is denoted by a and the weight in water by b, then the specific gravity of the material is calculated by the formula

$$\text{Sp. gr.} = \frac{a}{a - b}.$$

Such a determination should be accurate to about 5 units in the second decimal.

(*b*) If the material is non-homogeneous, as in the case of blast-furnace slag or gravel, but is composed of relatively coarse particles, the determination should be made on a 10-pound sample which is placed in a wire basket suspended from the hook of the large spring balance (§ 371) by means of a wire. Such a basket may readily be fashioned from a piece of $\frac{1}{4}$-inch square mesh wire, such as may be obtained at most hardware stores. A section 21 inches square will make a basket 7 inches square and 7 inches deep, by cutting out a piece 7 inches square from each corner, bending up the sides and wiring them together. A piece of stout wire may be made to serve as a handle. The empty basket should first be weighed in air and then submerged in a pail of water to a mark scratched on the wire suspending it. The first weight is called a and the second b. The basket should then be dried and approximately 10 pounds of the material weighed into it. This weight is called A. Sample and basket are finally weighed in water, submerged to the same mark on the wire as in the case of the empty basket. This weight is called B. From these weights the specific gravity of the product is ascertained by means of the following formula:

$$\text{Sp. gr.} = \frac{(A - a)}{(A - a) - (B - b)}.$$

Once weights a and b, which are constants, have been ascertained, determinations may be made with only two weighings.

(*c*) In the case of fine aggregates which will pass a $\frac{1}{2}$-inch screen, the specific gravity determination is best made by weighing out exactly 100 grams of the product on the small spring balance (§ 371). A 100-cubic-centimeter glass cylinder is then filled with water to the 50-c.c. mark, after which the 100-gram sample is introduced and stirred with a piece of wire until free from air bubbles. The water level is then read and the total number of centimeters called *a*. The difference in cubic centimeters between this reading and the first represents the number of cubic centimeters occupied by the sample. Its specific gravity is then ascertained by means of the following formula:

$$\text{Sp. gr.} = \frac{100}{a - 50}.$$

(*d*) If a non-homogeneous product is composed of both coarse and fine aggregates, a representative sample should be screened on a $\frac{1}{2}$-inch screen and the percentage weights retained, and passing should be recorded. The specific gravity of the coarse product is then determined by the wire basket method (§ 376*b*) and the specific gravity of the fine product is determined by means of the cylinder method (§ 376*c*). The following formula may then be used to ascertain the specific gravity of the entire product. In this formula W = per cent of coarse material and G its specific gravity; w = per cent of fine material and g its specific gravity.

$$\text{Sp. gr.} = \frac{100}{\frac{W}{G} + \frac{w}{g}}$$

377. Voids. (*a*) The per cent of voids in a mineral aggregate may be calculated from its weight per cubic foot (§ 375) and specific gravity (§ 377) by means of the following formula in which W = weight per cubic foot and G = specific gravity:

$$\%\ \text{Voids} = \frac{(62.43G - W) \times 100}{62.43G}.$$

(*b*) In the case of fine aggregates, such as sand, when it may not be convenient to make a determination of weight per cubic foot, the weight of 100 cubic centimeters may be determined by the same general method (§ 375), using a 100-cubic centimeter cylinder (§ 374*c*) and the small spring balance. The following formula is then used to determine the per cent of voids.

$$\% \text{ Voids} = \frac{100G - W}{G}.$$

TESTS OF BITUMINOUS MATERIALS

378. Penetration Test for Asphalt Cements. (*a*) The paving plant Inspector should be provided with the necessary apparatus for making penetration tests on asphalt cements which are to be used in asphaltic concrete or sheet asphalt mixes. This apparatus will ordinarily consist of the following:

A penetrometer complete with standard needle (Fig. 52).
A supply of round tin boxes[1] $2\frac{3}{16}$ inches in diameter and $1\frac{3}{8}$ inches deep.
A large metal kitchen spoon.
A tin or enamel ware dish at least 10 inches in diameter and 3 inches deep.
A 1-quart tin cup, iron tripod and alcohol burner, for heating water if necessary.
A thermometer reading from 0° C. to 110° C.

(*b*) There are a number of makes of penetration machines, all of which work on the same general principle and give equivalent results. The New York Testing Laboratory penetrometer, miniature size, is shown in Fig. 52. Briefly described, it consists of a rod holding the standard needle in a vertical position and weighted to 100 grams. This is

[1] This requirement is fulfilled by the American Can Company's gill style ointment box, deep pattern, 3-oz. capacity.

held in a loose fitting vertical sleeve or collar, by means of a spring plunger or clamp which is released by pressing the large knob, shown midway between the dial and needle. The dial is divided into 360 degrees, each of which represents 1 penetration unit, or $\frac{1}{10}$ millimeter vertical movement of a sliding gauge rod, which may be raised or lowered to make contact with the rod holding the needle. At the

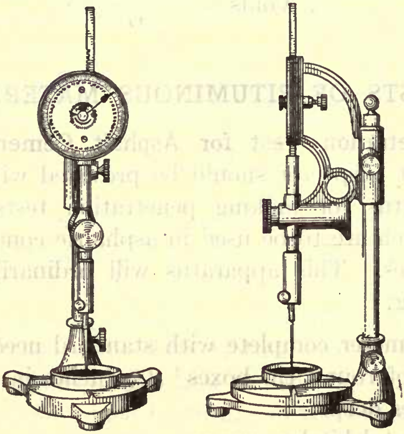

Fig. 52 New York Testing Laboratory Miniature Penetrometer

back of the dial a pin and spring device allows the pointer to be set at zero for any position of the gauge rod.

(*c*) The object of the penetration test is to ascertain the consistency of an asphalt cement by determining the distance that a standard needle weighted with 100 grams will penetrate into it during 5 seconds, when its temperature is exactly 25° C. (77° F.). The standard needle should be handled with care and frequently examined to see if its point has become blunted or turned, in which case it should be discarded and a new needle secured from the laboratory. When not in use its point should be protected by sticking it into a soft cork. The test specimen of asphalt cement

should be carefully prepared so that it is not hardened, through loss by volatilization, during its preparation. If the original sample has not been taken in a fluid condition from the melting kettle, it should be completely melted at as low a temperature as possible and stirred until homogeneous and free from air bubbles. It should then be poured into one of the small tin boxes and allowed to cool to air temperature, after which box and contents should be placed under water, in the large dish and maintained at a temperature of 25° C. for not less than 30 minutes, and perferably 1 hour. In order to maintain a temperature of 25° C. in warm weather, it may be necessary to add a small amount of cold well water or ice water to the contents of the large dish from time to time, and in cold weather, the addition of hot water may be required.

(*d*) The test is made by placing the base of the penetrometer in a level position under water in the large dish. The box of asphalt cement is then placed in a firm position on the base of the machine directly under the needle, still covered with water at 25° C. The rod holding the needle is then carefully lowered until the point of the needle just makes contact with the surface of the asphalt. This can best be seen by having the light so located that the needle will be reflected from the surface of the asphalt. After thus setting the needle, the gauge rod is brought in contact with the needle rod, and the pointer on the dial set at zero. The needle rod is then released for five seconds by pressing the spring plunger. This is most conveniently done by counting 11 ticks of a metronome set to beat $\frac{1}{2}$-second intervals. The needle should be released at the first count and clamped at the eleventh. The depth of penetration is ascertained by again bringing the gauge rod in contact with the needle rod and noting the reading on the dial. At least three tests should be made at points on the surface of the sample not less than $\frac{3}{8}$ inch from the sides of the container and not less than $\frac{3}{8}$ inch apart. After each test the needle should be

carefully wiped toward its point, with a clean dry cloth, to remove all adhering asphalt. The reported penetration should be the average of at least three tests whose values should not differ more than four points between maximum and minimum.

379. Float Test for Tars. (*a*) If refined tar is used at a paving plant, its consistency may most conveniently be obtained by means of the float test which requires the following apparatus:

A float test apparatus (Fig. 53).
Two 1-quart, tin cups.
A large metal kitchen spoon.
A kitchen knife.
An iron tripod and alcohol burner.
A stop watch.
A smooth brass plate about 2 inches square.
Two thermometers reading from 0° C. to 110° C.

(*b*) The float apparatus shown in Fig. 53 consists of an aluminum saucer and a conical brass collar, or mold, which may be screwed into a hole in the bottom of the saucer. In order to make quick check tests, it will be found convenient to have two molds. In making the test, a small sample of the tar is first carefully melted, by gently warming it in the metal spoon, at as low a temperature as possible. It is then poured into the conical brass mold, which has been placed with the small end down on the brass plate. The plate may first be very lightly greased with a film of vaseline to prevent the tar from adhering to it. The mold is slightly more than filled level with the top, and after the tar has cooled all excess is removed by means of the knife which has been warmed in the flame of the burner. Mold and plate should then be placed in one of the tin cups containing ice water maintained at 5° C. and allowed to remain in the bath for at least 15 minutes. Meanwhile, the other cup is filled about three-fourths full of water, placed on the

tripod and heated to 50° C., which temperature is carefully maintained, to within one-half a degree, throughout the test. After the test specimen has been kept in the ice water for at least 15 minutes, the mold is removed from the plate and screwed tightly into the saucer, and is then immediately floated in the hot bath. As the plug of bituminous material becomes warm and fluid, it is gradually forced upward and out of the mold, until water gains entrance to the saucer and causes it to sink. The time in seconds elapsing between placing the apparatus on the water and when

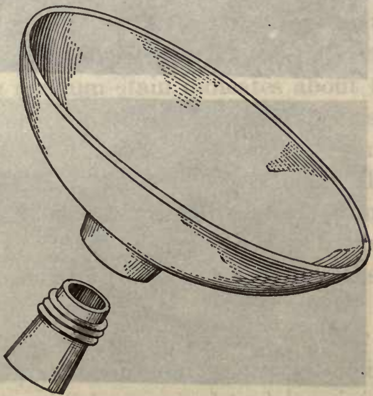

Fig. 53 New York Testing Laboratory Float Apparatus

the water breaks through the tar is determined by means of a stop watch and is reported as a measure of the consistency of the tar.

380. Pat Test for Sheet Asphalt Mixtures. (*a*) At a paving plant in which sheet asphalt surface mixture is being manufactured, samples of the hot mix are subjected to the pat test, as a guide in ascertaining the proper percentage of asphalt cement which should be used. This test requires the following apparatus:

A wooden paddle with blade about 6 inches long, 4 inches wide and ½ inch thick.

A supply of unglazed Manila wrapping paper.
An ordinary mason's trowel for sampling.
An armored thermometer (§ 386).

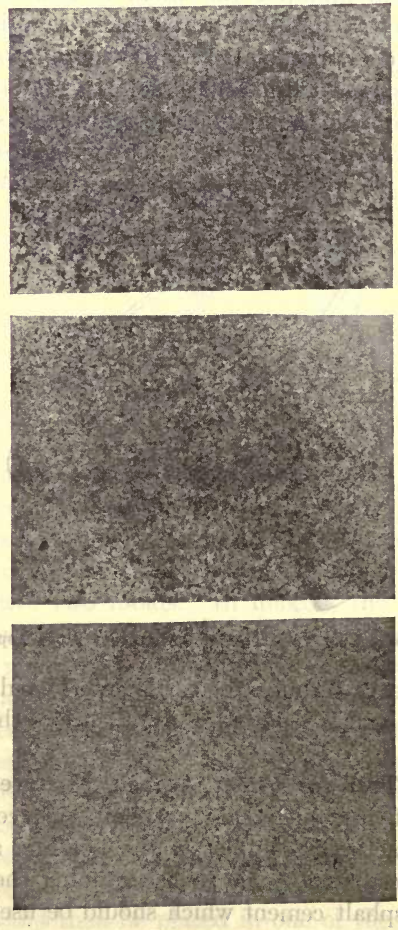

Fig. 54 Pat Stains

(*b*) The test is made by taking a small sample of the hot mix from the material, delivered from the mixer, and not-

ing the temperature of the batch or load. The sample is immediately placed upon a sheet of the manila paper, resting upon a flat board or bench top. The paper is then folded over the sample and the flat of the paddle pressed heavily against it. After compressing the sample, the paper is struck a sharp blow with the paddle, then opened and the pat removed. The character of the stain left upon the paper is examined and, considered in connection with the temperature of the sample, indicates whether or not the proper percentage of bitumen is present. Three classes of stains obtained from pats taken at a temperature of about 300° F. are shown in Fig. 54. The lightest stain indicates a deficiency of asphalt and the darkest an excess of asphalt. The medium stain indicates about the proper per cent of asphalt. Considerable experience is necessary to properly interpret the results obtained from the pat test, and the temperature of the material should always be taken into account. If the proper per cent of bitumen is present, stains which show only the imprint of individual sand grains indicate a deficiency of filler which, if present in proper amount, will produce a more uniform stain.

381. Moisture in Wood Block. (*a*) For checking the amount of oil present in creosoted wood block (§ 322*b*) the plant Inspector may be required to determine the amount of moisture in both the treated and untreated wood. A fairly close approximation of this factor may be obtained by the following method which calls for the apparatus listed below.

A one-half pint iron retort.

A bent glass condensing tube about 30 inches long with cork connection to the retort.

A separating funnel, capacity 120 cubic centimeters with outlet graduated in fifths of a cubic centimeter.

A balance,[1] capacity 100 grams, sensitive to 0.1 gram.

[1] If such a balance is not at hand the small spring balance (§ 371) will be sufficiently accurate for rough determinations.

Two iron stands with ring support and two clamps.

A Bunsen burner with rubber tubing, or a large alcohol burner.

A supply of water saturated xylol.[1]

(*b*) In making the test, two average cubic feet of untreated block are selected and both weighed. These weights

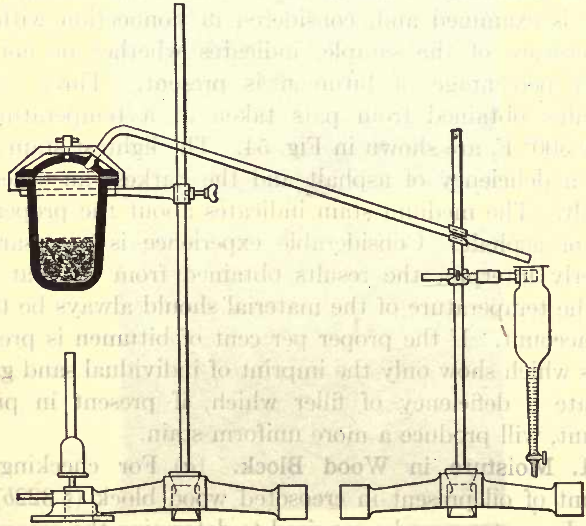

Fig. 55 Apparatus for Determining Moisture in Cresoted Wood Block

should be approximately the same. One cubic foot is suspended in a wire cage in the treating tank (§ 322*b*) and subjected to the regular treatment with creosoting oil. The other cubic foot is taken to a wood drilling machine and a large number of borings made quickly. These borings should be thoroughly mixed and a 10-gram sample taken and rapidly weighed. The sample is then placed in the iron retort and covered with water-saturated xylol. The top of

[1] Water saturated xylol is prepared by heating a mixture of xylol and water with frequent shakings and then removing the water by means of a separatory funnel.

the retort is then clamped on, using a paper gasket, and the apparatus set up as shown in Fig. 55, care being taken to secure a tight connection between the retort and condensing tube. Heat is then gradually applied until all of the xylol has distilled over at the rate of about 2 drops per second. Moisture present in the wood will be carried over with the xylol and upon standing will separate from the distillate, in the graduated portion of the funnel where its volume in tenths of a cubic centimeter may be read off directly as per cent of the original sample. After treatment the other cubic foot of wood is first weighed and then subjected to the same test, the per cent of water present being ascertained.

(*c*) The amount of oil actually absorbed is then calculated as follows, where X equals pounds of oil per cubic foot of wood, W equals weight of untreated wood, in pounds per cubic foot, W' equals weight of treated wood, in pounds per cubic foot, p equals per cent of moisture in untreated wood and p' equals per cent of moisture in treated wood.

$$X = W' - \frac{W}{100}(100 - p) - \frac{p'W'}{100}.$$

Thus for example, suppose the weight per cubic foot of untreated wood is 50 pounds and it contains 16 per cent of moisture, while the weight of treated wood is 60 pounds per cubic foot and it contains 2 per cent of moisture. Then the number of pounds of oil per cubic foot of treated wood is

$$60 - \frac{50}{100}(100 - 16) - \frac{2 \times 60}{100} = 16.8 \text{ pounds.}$$

382. Absorption of Asphalt Block. A rough field test fox determining the approximate absorption of asphalt block may be made by selecting three dry block which will pass visual inspection (§ 318) and weighing them separately on the large spring balance (§ 371*a*). They should then be immersed in water for 7 days, at the end of which time they are removed, carefully surface dried and again weighed.

The difference in weights, before and after immersion, is calculated for each block as per cent of water absorbed on the basis of the dry weight. An average of the three tests should be reported as the final result.

383. Specific Gravity. (*a*) Ordinarily the specific gravity of bituminous materials, such as oils, asphalts, and refined tars, should be determined by the laboratory but at times the Inspector may wish to know the approximate specific gravity of a material, when a laboratory report is not available. In such case it is well to work with as large a sample as possible and to have the temperature of the material approximately 25° C. (77° F.). For this purpose an ordinary conical top one gallon oil can may be used. The clean dry can is first weighed empty on the large spring balance (§ 371*a*) and the pointer set at zero. It is then completely filled with water and the weight of the water recorded. It is next emptied and when dry is completely filled with bituminous material. In the case of a semi-solid product it will first be necessary to render it fluid, by the application of heat. Upon cooling the material will shrink and additional material must then be poured in until, when cool, the can is completely filled. The weight of the contents of the can is then ascertained and this weight divided by the weight of water originally obtained gives the approximate specific gravity of the material.

(*b*) In the case of bituminous materials which are sufficiently solid to be handled, a ball or fragment weighing approximately 100 grams may be weighed in air and in water and its specific gravity ascertained exactly as described for non-bituminous materials (§ 376*a*). The specific gravity of an asphalt block or of not less than a 10-pound sample of compressed bituminous aggregate or pavement sample may be determined in the same manner with the large spring balance (§ 371*a*).

384. Voids in Compressed Bituminous Paving Mixtures. The per cent of voids in compressed bituminous paving mix-

tures may be calculated if the specific gravity and per cent by weight of each constituent are known, as well as the specific gravity of the compressed mixture. This first involves a calculation of the maximum possible density which is given by the following formula in which D represents the maximum possible density, W, W^1, W^2, etc., represent the weight per cents of the various constituents, and G, G^1, G^2, etc., their respective specific gravities.

$$D = \frac{100}{\frac{W}{G} + \frac{W^1}{G^1} + \frac{W^2}{G^2}}.$$

Thus, for example, if a bituminous aggregate is composed of 94 per cent of broken stone with a specific gravity of 2.7 and 6 per cent of asphalt with a specific gravity of 1.04 the maximum possible density of the mix is

$$\frac{100}{\frac{94}{2.7} + \frac{6}{1.04}} = 2.46.$$

If the actual density of the compressed mix as found is called d then the per cent of voids in the mix is ascertained by the following formula:

$$\% \text{ Voids} = \frac{100(D - d)}{D}.$$

Thus, if in the example above given the actual density of the mix is found to be 2.30, the per cent of voids would be

$$\frac{100(2.46 - 2.30)}{2.46} = 6.5\%.$$

MISCELLANEOUS EQUIPMENT

385. Sampling. No special sampling devices are ordinarily needed by the Inspector although when required to sample large quantities of material at one time, such as sand or cement, tube samplers will be found convenient. Special forms of thief samplers may also prove useful for sampling bituminous materials in large tanks. Whatever

device or method may be used for sampling, the Inspector should always remember that no matter how carefully and accurately tests are conducted, test results can be no more representative than the samples themselves. It is, therefore, most important that the relatively small quantity of material in the sample be so selected that it is actually representative of the larger bulk of material sampled. Great care should be taken that samples are not contaminated with dirt or other extraneous matter and that the sample containers are perfectly clean and dry before filling. Immediately after filling, the sample containers should be closed and properly marked (§ 389) for identification. Samples should be packed for shipment in such manner that, during transit, leakage of contents, breakage, or contamination by packing material, is entirely prevented as well as obliteration or removal of identification marks.

386. Thermometers. While the ordinary unprotected laboratory thermometer is best suited for use in connection with the plant inspection tests here described, it is unsuitable for obtaining records of the temperature of material as prepared for use in certain bituminous types of construction. Large stationary kettle thermometers should preferably be supplied, by the contractor, for recording the temperature of all bituminous materials heated in kettles or tanks. For ascertaining the temperature of heated aggregates and bituminous mixes, the Inspector should be provided with an armored thermometer with a temperature range suited to the particular requirements of the job. For ordinary paving plant and street inspection, a ten-inch armored thermometer with scale graduated from 200° to 650° F. in 5° divisions is very serviceable. Such a thermometer is manufactured particularly for asphalt testing,[1] and may be plunged into a heated bituminous aggregate to a depth of $4\frac{1}{2}$ inches. The lower part of the stem is com-

[1] Taylor Instrument Co., Rochester, N. Y., Cat. No. 1107, Asphalt Testing Thermometer.

pletely protected by a metal casing and the bulb is immersed in a mercury packing. The upper part of the stem is also protected by the metal casing, except for the reading face. After use and while still warm, the thermometer should be wiped with a clean cloth and any adhering bitumen should be removed with kerosene.

387. Measurement and Visual Inspection. The Inspector should ordinarily be provided with a 50-foot steel tape graduated on one side in feet and inches and on the other in feet and tenths of a foot. A single hinge foot rule graduated in a similar manner will be useful. In the case of brick or block inspection, a small wooden gauge with the three specified dimensional limits marked or notched thereon will also be useful. Such a gauge may be made in a few minutes' time by the Inspector on the job. A small pocket magnifying glass may in some cases prove a valuable part of the Inspector's equipment. In addition a string level, a short plumb line and a short stout screw driver will at times prove most handy accessories for the purpose of measurement.

388. Selection of Equipment. It is quite essential that the Inspector's equipment be as light and compact as possible and practically all of the testing apparatus listed above has been selected from this standpoint. Together with additional equipment listed under the various types of pavement, practically everything that the Inspector may need for a single job, with the exception of sample containers in quantity, may be packed in an ordinary suitcase and in most instances considerably less space than this will be required. This statement does not, of course, include such articles as templates, spades, shovels, etc., which if needed may be made or borrowed on the job. Just what will be needed, for a given piece of work, will depend largely upon specification requirements and the accessibility of the testing laboratory. Judicious selection made upon this basis will keep the Inspector's equipment to the minimum of weight and bulk.

CHAPTER XVIII

RECORDS AND REPORTS

SAMPLES

389. Identification. Each sample of material submitted to the laboratory should be plainly identified by a mark or number which should never be duplicated for any other sample in connection with the same job. In many instances it is impossible to place such a mark directly on the material and it is then necessary to mark the container or to securely attach to the container an identification tag bearing the mark. The outside wrapping of a sample, shipped by mail or express, should never be depended upon to carry the identification mark as the wrapping is likely to be lost or destroyed before the mark is recorded by the laboratory. Care should be taken that identification marks are perfectly legible and that during transit they will not be obliterated or defaced. The Inspector should record, in his diary, for future reference the marking of each sample submitted together with the general information forwarded the laboratory in connection with the sample.

390. General Information. A notice of the shipment of each sample should be promptly mailed to the laboratory together with such information as should be made a matter of record or which will assist the laboratory in determining what interpretation should be placed upon test results. Such information may include any or all of the following items:

Identification mark.

Name or type of material including trade name, if any.

Name and address of producer, consignor, or owner of the deposit in case of natural products.

Location of plant or deposit from which material is shipped or secured.

Purpose for which sample is to be tested, such as suitability for a given use, or conformity with a given specification which should be clearly indicated.

Name and location of road or street on which the material is proposed for use or has been used. (In the latter case the exact location of use should be noted.)

Place and date of taking sample.

Quantity of material represented by sample.

Place from which sample was taken, such as quarry, crusher, bin, pit, plant, car, wagon, barge, storage pile, mixer, tank, barrels, drums, distributor, or pavement.

In case of shipment by freight, date of such shipment or date of receipt at destination, together with car number.

Date material used, or to be used if satisfactory.

General comments and queries, including any observation that the Inspector cares to make relative to his own suspicions or tests, and any question regarding the sample which he wishes to have specifically answered by the laboratory.

In well-organized work printed forms are frequently used in connection with the submission of samples. Such forms contain headings, similar to those above listed, under which the Inspector is expected to enter the desired information. It is advisable for the Inspector to retain a carbon copy of all information which he furnishes the laboratory.

391. Location Where Used. Whenever material which has been sampled for laboratory or field tests is used on a job the Inspector should enter, in his diary, the exact location on the road where the material is used together with the identification mark and name of the sample. Such a record will be of great service in the later correlation of

service results with the characteristics of the material, as determined by test. Station numbers may be used to locate positions on the road but, in addition to this, it is well to also note distinguishing landmarks or roadside features, such as the number or name of a building, the intersection of another highway, the name of the owner of adjacent property, the distance from the upper or lower end of a grade, the distance from a gate post or fence corner, or from some particularly prominent tree, etc.

392. Test Reports. The Inspector should retain copies of all test reports furnished him by the laboratory and should enter in his diary the results of all field tests which he himself makes. He should also include the results of field tests in reports which he may make to the Engineer from time to time.

PROGRESS OF WORK

393. Daily Records. A daily record of progress of work should be kept by the Inspector and a daily report of such progress should be forwarded the Engineer. Special report forms are often used for this purpose in which the work done during the day is shown by station distances for the various items of work such as rough grading, fine grading construction of foundation, construction of wearing course, trimming shoulders, construction of curb, gutters, etc., according to the class of work involved. Upon receipt of such report by the Engineer the record is taken off upon a large chart showing the entire length of the road or pavement divided into stations. The Engineer thus has constantly at hand a diagram showing the status of the work at a glance.

394. Weekly Summaries. Weekly summaries of progress of work are in general similar to the daily records but may be more complete in certain details which are recorded in the Inspector's diary. Thus quantities of materials re-

ceived on the job, quantities of materials used and, in certain cases, items of work not shown on the daily reports are recorded, together with a statement of the number and kind of samples submitted to the laboratory, a tabulation of field tests made by the Inspector and, in some cases, cost data relative to labor and materials.

395. Paving Plant Operation. The plant Inspector should forward the Engineer daily reports of plant operation showing the results of tests made on the various materials, temperature records, actual weights and proportions of the constituents used in each type of mix, total quantity of each mix produced and sent out by the plant, and the number of square yards laid with each type of mix. No single report form is well suited for all kinds of paving work, unless it contains items which may not apply to the particular class of pavement under inspection. The proper form is, therefore, usually prepared by the Engineer to meet his own requirements. The following form in connection with sheet asphalt work will, however, serve as an example of what may be required of the plant Inspector in the way of daily reports.

DAILY REPORT OF PLANT INSPECTOR FOR SHEET ASPHALT PAVEMENT

Location of work.................................Date.........
Binder Mix, No. boxes........No. loads........Sq. yds. laid.......
Surface Mix, " " .... " " .... " " " ....

ASPHALT CEMENT USED

Material	Kind	Lab. No.	Proportions		Penetration A. C.		
			Binder	Surface			
Asphalt			100 lbs.	100 lbs.	Binder		
Flux					Surface		

BINDER MIX

Material	Box Weight	Per cent	Box Weight	Per cent
Stone Sand A. C.				

SURFACE MIX

Material	Box Weight	Per cent	Box Weight	Per cent
Sand Filler A. C.				

BINDER AGGREGATE

Size, Per cent	Stone	Sand	Mix
1 inch–1½ inches ½ inch–10 mesh Passing 10 mesh			

HOT SAND

Time				
Size	Per cent	Per cent	Per cent	Per cent
10–20 20–30 30–40 40–50 50–80 80–100 100–200 Passing 200				

TEMPERATURES

Time A. C. Stone Binder Mix Sand Surface Mix						

Samples submitted to Lab. Stone........Sand........Filler.........
R. A.........Flux........A. C.........

....
Signature

QUANTITIES OF MATERIAL

396. Material Received. The Inspector should keep in his diary a record of quantities of various materials received on the job and, in case of distribution along the sides of the road, he should note the spacing of individual lots as a check upon estimates of quantities needed to complete the work in accordance with specification requirements. Such records should be included in his daily or weekly reports together with a statement of samples taken and tested or submitted to the laboratory.

397. Material Used. No material, requiring laboratory test, should be allowed to be used until accepted upon the basis of test results, unless its use without previous testing is specifically authorized by the Engineer. The Inspector should see that all rejected material is promptly removed from the site of work and that it is not later used on any part of the job. Deductions for such rejections and removals should be made from the record of material received in working up his weekly summaries. A daily record should be kept of quantities of materials actually used together with the yardage or volume of each class of work performed. The use of materials which, upon the basis of field tests, fail to pass the specification requirements should be allowed only at the risk of the Contractor with the warning that the work in which it is so used may be rejected at the discretion of the Engineer, who will decide upon the importance of the variations from specification requirements. The use of any material should not, however, be stopped upon the basis of field test results obtained from a single sample. Material variation from specification requirements should always be checked by tests made upon one or more additional samples. The daily record, of each material used, may be entered upon the daily report of progress of work and should, for each material, show the number or identification mark of the sample or samples which represent the particular lot of material.

398. Checks on Quantities. The Inspector should check quantities of materials shown on bills of lading, etc., by his own measurements of weight or volume, a record of which should be kept in his diary. The various diagrams given under the different types of work may be of assistance to him in such determinations, but as they will not exactly fit all cases it will frequently be advisable for him to carry in his diary small charts or diagrams which he may prepare to meet the conditions of the particular job under inspection.

COST DATA

399. Labor. When work is done upon a force account basis it is necessary to keep a record of the force employed and to report daily the number of hours work of each employee. When a large force is employed, and the force is scattered over a considerable length of highway, the services of a timekeeper will be needed for this purpose, but on small jobs where the force is concentrated the Inspector is sometimes required to submit a daily report showing the number of each class of labor, the hours of work performed, the rate of compensation and the amount of money involved. For this purpose he should be provided with a special report form. In addition to this he may be required to show the distribution of cost among various items of the work, such as spreading stone, distributing bituminous material, laying brick, etc.

400. Materials. On certain jobs it may be necessary to keep a record of the cost of materials used. As the quantities of materials used should always be recorded by the Inspector under the various items of work, the distribution of costs is a simple matter provided measurements are made upon the proper unit basis and the unit price is known.

GENERAL RECORDS

401. The Inspector's Diary. The Inspector's diary should be his constant companion and in it he should keep a complete daily record of all matters pertaining to his work, especially such data as will be included in his reports to the Engineer. The entries should be neat and legible and all calculations of quantities and costs should be clearly shown, together with details and calculations in connection with all field tests which he may make. By so doing, possible errors may be most readily located and corrected. The diary should be of pocket size. If of the loose leaf type the

pages should be numbered consecutively so that once removed from the cover they may be reassembled in proper sequence.

402. Deviation from Specifications. The Inspector should always carry with him, for reference, a copy of the specifications. All deviation from the specification requirements should be noted in his diary, together with notation of his action in connection with same, such as acceptance of material or work with warning to the contractor, rejection of material, etc.

403. Special Instructions from the Engineer. All special instructions from the engineer not received in writing should be dated and entered in the Inspector's diary as a record of what he is expected to do under the conditions covered by such instructions. This is particularly advisable in case the Engineer sees fit to fix certain allowable limits, within the specification requirements, or agrees with the Contractor to allow certain deviations from the specifications, or places a definite interpretation upon some requirement which may appear to be indefinite. Upon the first opportunity the Inspector should request the Engineer to O.K. such instructions as entered in his diary.

404. Report Forms. Report forms should be so devised as to show clearly and concisely all of the information required by the Engineer. It is impracticable to utilize a single form for all classes and conditions of work but the general arrangement and subject matter is illustrated in the following daily report form, adapted for use in connection with the construction, by contract, of a bituminous macadam pavement upon an old reshaped macadam road, which is made to serve as foundation.

INSPECTOR'S DAILY REPORT ON BITUMINOUS MACADAM

Location of work.................... Date....................
Weather.......................... Temperature.............

Progress of Work

	From Station	To Station	Remarks
Reshaping old road......			
Placing broken stone......			
1st application bit. mat..			
Seal coat..................			
Trimming shoulders........			

Materials

Material	Used			Received	
	Sample No.	Total	Sq. yd.	Quantity	Sample No.
New stone in foundation....					
Coarse stone wearing course.					
Chips......................					
Bit. mat., 1st application....					
Bit. mat., seal coat..........					

Testing and Sampling

Tests of Broken Stone

Grade............................. Sample No........................			
Passing........ Retained on........ " .... " " .... " .... " "			

Submitted to Laboratory

Material	Sample No.

Temperature of Bituminous Material

Time	Temperature

Remarks: . . . .
. . . .
. . . .
. . . .
. . . .

. . . .
Signature

CHAPTER XIX

TYPICAL MATERIAL REQUIREMENTS

Unless otherwise indicated by footnotes, all of the following specification requirements are tabulated from typical specifications of the U. S. Bureau of Public Roads.[1] They serve to illustrate common physical and chemical characteristics determined by test which are commonly included in specifications for various types of materials. When a test value is followed by a + sign, the sign should be interpreted as meaning not less than the value given. When a test value is followed by a – sign, the sign should be interpreted as meaning not more than the value given.

NON–BITUMINOUS MATERIALS

405. Broken Stone.

Type of Road	Total Per Cent Passing Screens								French coef.	Toughness
	3″	2½″	2″	1½″	1″	¾″	½″	¼″		
WATERBOUND									7+	
Bottom Course	95+	25–75	15–							
Top course			95+	25–75	15–					
Screenings					95+			40–80		
BITUMINOUS SURFACE										
Coarse chips					95+			15–		
Fine chips							85+	15–		
BITUMINOUS MACADAM									7+	
Coarse stone			95+	25–75	15–					
Chips					95+			15–		
BITUMINOUS CONCRETE (One-size stone)									8	8
Coarse stone					95+	25–75		15–		
Chips for seal coat							95+	15–		

[1] U. S. Dep't. Agriculture Bulletins 691 and 704.

405. Broken Stone — *Continued.*

Type of Road	Total Per Cent Passing Screens 3″	2½″	2″	1½″	1″	¾″	½″	¼″	French coef.	Tough-ness
BITUMINOUS CONCRETE...									8	8
(Coarse graded)										
Coarse aggregate[1].......					95+	25–75		15–		
Chips for seal coat......							95+	15–		
BITUMINOUS CONCRETE....										
(Topeka type)										
Stone aggregate[2]........							95+	80–		
SHEET ASPHALT BINDER. .										8
Stone aggregate[2]........					95+					
CEMENT CONCRETE BASE. .										
Coarse aggregate[1].......	95+			40–75				15–		
CEMENT CONCRETE PAVE. .									8	8
Coarse aggregate[1].......			95+		40–75			15–		

[1] For fine aggregate see § 407. [2] For sand aggregate see § 407.

406. Gravel.

Type of Road	Total Per Cent Passing Screens 3″	2″	1½″	1″	¾″	½″	¼″	Passing 200-mesh	Cementing Value
WATERBOUND..................									
Bottom Course									
Entire aggregate............	95+						25–50		
Coarse ag. ret. on ¼″........			25–75						
Fine ag. passing ¼″..........								15–35	50+
Top (or both) courses.........									
Entire aggregate............		95+					25–50		
Coarse ag. ret. on ¼″........				25–75					
Fine ag. passing ¼″..........								15–35	50+
BITUMINOUS SURFACE..........									
Pea gravel..................						85+	15–		
BITUMINOUS CONCRETE..........									
(Coarse graded)									
Coarse aggregate[3]..........				95+	25–75		15–		
Gravel for seal coat.........						95+	15–		
CEMENT CONCRETE BASE........									
Coarse aggregate[3]..........	95+		40–75				15–		

[3] For fine aggregate see § 407.

407. Sand.

Type of Road	Passing ¼″ Screen	Per Cent Passing Mesh Sieve 10	20	40	50	100	200	Per Cent by Elutriation	Mortar Strength
Bituminous Concrete (Coarse graded) Fine aggregate[1]	100			30–70			10–		
Bituminous Concrete (Topeka type) Sand aggregate[2]	100						10–		
Sheet Asphalt Binder[3] Sand aggregate[2]	100								
Cement Concrete Base Fine aggregate[1]	100		20+		50–	10–		5–	75+
Cement Concrete Pavement Fine aggregate[1]	100		50–80		20–	5–		3–	100+
Brick or Block									
Sand cushion	100							5–	
Mortar cushion[4]	100								75+
Grouting sand[4]		100	80+				5–		75+

[1] For coarse aggregate see §§ 105 and 106. [2] For stone aggregate see § 105.
[3] For sand grading for surface mixture see § 279.
[4] A. S. T. M. Tentative Specifications recommended by Com. D–4 in 1919.

BITUMINOUS MATERIALS

408. Oil and Asphalt Products for Surface Treatment.

Material	Heavy Distillate	Heavy Crude or Cut-back	Cut-back Asphalt[1]	Residual
Use	Dust Palliative	Cold Surface Treatment	Cold Surface Treatment	Hot Surface Treatment
Specific gravity 25° C.	0.940 –	0.935–0.970	0.890 +	0.980 +
Flash point, open cup	100° C. +	50° C. –		80° C. +
Specific visocity, 25° C.	10 –	80–120	25–35	
" " 100° C.				60 –
Float test 32° C.				60 sec. +
Loss 163° C., 5 hours	15% –	30% –	30–40%	15% –
Float 50° C. on residue	Liquid	90 sec. +		110 sec. +
Penetration 25° C. of residue			50–85	
Solubility in carbon disulphide	99.8% +	99.5% +	99.5% +	99.5% +
Insol. in 86° B. naphtha		6.0% +		6.0% +
Sp. gr. distillate to 200° C.			0.73–0.78	

[1] Am. Soc. for Municipal Improvements, 1919.

409. Tar Products for Surface Treatment and Cold Patching.

Material	Light Refined[1]	Refined or Residual	Cut Back
Use	Cold Surface Treatment	Hot Surface Treatment	Cold Patching
Specific gravity 25° C.	1.100–1.180	1.130 –	1.100–1.200
" viscosity 40° C.	10–35[2]		40–70
Float test 32° C.		60–150	
Total distillate to 170° C.	5% –	1% –	2% –
" " " 270° C.	30% –	15% –	15–25%
" " " 300° C.	40% –	25% –	30% –
Solubility in carbon disulphide	90% +	85% +	80% +

[1] Am. Soc. for Municipal Improvements, 1918.

[2] A range of 5 allowed for any one job, exact limits to be controlled by climatic conditions and type of road treated.

410. Asphalt Emulsion for Cold Patching.[1]

Total distillate to 260° C.	32 % –
Oil distillate to 260° C.	2 % –
Tests on residue from distillation to 260° C.	
Specific gravity 25° C.	1.01 +
Penetration at 25° C.	150–250
Solubility in carbon disulphide	98.5 % +
Insoluble in 76° B. naphtha	8–28 %
Fixed carbon	6–15 %
Ash	1 % –
Paraffin scale	4.7 % –
Ductility at 25° C.	40 +

411. Refined Tars for Bituminous Macadam or One-size Stone Bituminous Concrete.

Conditions	Specific Gravity at 25° C.	Float Test at 50° C. (seconds)	Per Cent Total Distillate to 170° C.	to 270° C.	to 300° C.	Melt. Point Resid. ° C. (Ring and Ball).	Per Cent Soluble in Carbon Disulphide
Northern U. S.							
Low carbon tar	1.15–1.20	120–150	1–	10–	20–	65+	97+
Medium carbon tar	1.20–1.25	"	"	"	"	"	80–97
Southern U. S.							
Low carbon tar	1.15–1.20	150–180	1–	10–	20–	65	97+
Medium carbon tar	1.20–1.25	"	"	"	"	"	80–97

[1] New York State Highway Commission, 1919. Material must flow readily from bung of barrel. Must not separate when agitated for 3 minutes with clean washed and drained trap rock in proportions of $1\frac{1}{4}$ oz. emulsion to 1 pound of small broken stone.

412. Asphalt Cements for Construction.

Type of Road	Sp. Gr. 25° C.[1]	Flash Point ° C. (Open Cup)	Melting Point ° C. (Ring and Ball)[2]	Penetration at 25° C.	5 Hours Loss 163° C.	Pen. of Residue at 25° C.	Per Cent Soluble in Carbon Disulphide	Per Cent Organic Insoluble	Per Cent Inorganic Insoluble
Bituminous Macadam									
1. Northern U. S.[3] Oil Asphalt	1.000+	175+	35–55	120–150	1%−	70+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.025–1.05	"	35–45	"	3%−	60+	95.0+		1.5–2.5
2. Middle Belt U. S. Oil asphalt	1.000+	175+	35–55	90–120	1%−	60+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.03–1.05	"	40–50	"	3%−	45+	95.0+		1.5–2.5
3. Southern U. S. Oil Asphalt	1.010+	175+	40–60	80–90	1%−	50+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.05–1.07	"	40–50	"	3%−	40+	95.0+		1.5–3.0
Bituminous Concrete (One size-stone) Northern U. S. (Same as 3)									
4. Southern U. S. Oil asphalt	1.010+	175+	40–60	70–80	1%−	45+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.05–1.07	"	40–50	70–80	3%−	35+	95.0+		2.0–3.5
Bituminous Concrete (Coarse graded) Northern U. S. (Same as 4)									
5. Southern U. S. Oil Asphalt	1.010+	175+	40–60	60–70	1%−	40+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.05–1.07	"	45–55	60–70	3%−	30+	94.5+		2.0–3.5
Bituminous Concrete (Topeka type) Northern U. S. (Same as 5)									
6. Southern U. S. Oil Asphalt	1.020+	175+	40–60	50–60	1%−	30+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.05–1.07	"	45–55	50–60	3%−	25+	94.0+		2.5–4.0
Sheet Asphalt. Northern U. S (Same as 6) Fluxed Trinidad asphalt	1.20–1.25	175+	45–55	50–60	3%−	25+	68.0+		20–30
7. Southern U. S. Oil asphalt	1.020+	175+	45–65	40–50	1%−	25+	99.5+	0.2−	
Fluxed Bermudez asphalt	1.055–1.075	"	45–55	"	3%−	20+	94.0+		2.5–4.0
Fluxed Trinidad asphalt	1.21–1.27	"	50–60	"	"	"	65.0+		22–32
Joint Filler. Oil Asphalt, poured	0.980+	200+	80+	30–50[4]	1%−	20+	99.5+	0.2−	
" " for grout[5]			54–63	60–100	3%−	50+			

[1] Maximum variation of 0.02 allowed for oil asphalt on any one job. [3] Only for extreme climatic conditions and light traffic.
[2] Maximum variation of 10° C. allowed for oil asphalt on any one job. [4] Penetration at 0° C. 20+. Penetration at 46° C. 100−.
[5] Borough of Manhattan, New York, 1914. Solubility in carbon tetrachloride not less than 38.5%; ductility at 25° C. not less than 40; penetration at 38° C. not more than three times penetration at 25° C.

413. Tar Pitch for Grout for Joint Filler.[1]

Specific gravity at 60° F. (15.5° C.)........	1.23–1.33
Melting point (cube method in water)....	115–135° F.
Insoluble in hot benzol or chloroform.....	20–35 %
Inorganic matter........................	0.5 % –
Ductility at 77° F. (25° C.)...............	60 c. m. +

414. Creosoting Oil.[2]

Material	Coal Tar Oil Distillate 65 % + Ref. or Filtered Tar 35 % –	Coal Tar Distillate	Water Gas Tar[3]
Water..............................	3 % –	3 % –	3 % –
Insoluble in benzol..................	3 % –	0.5 % –	2 % –
Specific gravity 38° C................	1.07–1.14	1.06 +	1.11–1.14
Total water free distillates			
To 210° C..........................	5 % –	5 % –	5 % –
" 235° C..........................	25 % –	15 % –	15 % –
" 315° C..........................			40 % –
" 355° C..........................			25 % +
Sp. gr. distillate 235°–315° C. at 38° C.	1.03 +	1.03 +	
" " " 315°–355° C. " "	1.09 +	1.09 +	
" " total distillate to 355° C. at 38° C..........................			0.99–1.03
Float test at 70° C. on residue if 35 % +	80 sec. –		
" " " " " " " 10 % +		50 sec. –	
Coke residue.........................	10 % –	2 %	

[1] Am. Soc. for Municipal Improvements, 1918.

[2] Amer. Soc. for Testing Materials 1918, Tentative.

[3] Presented to Society for information.

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